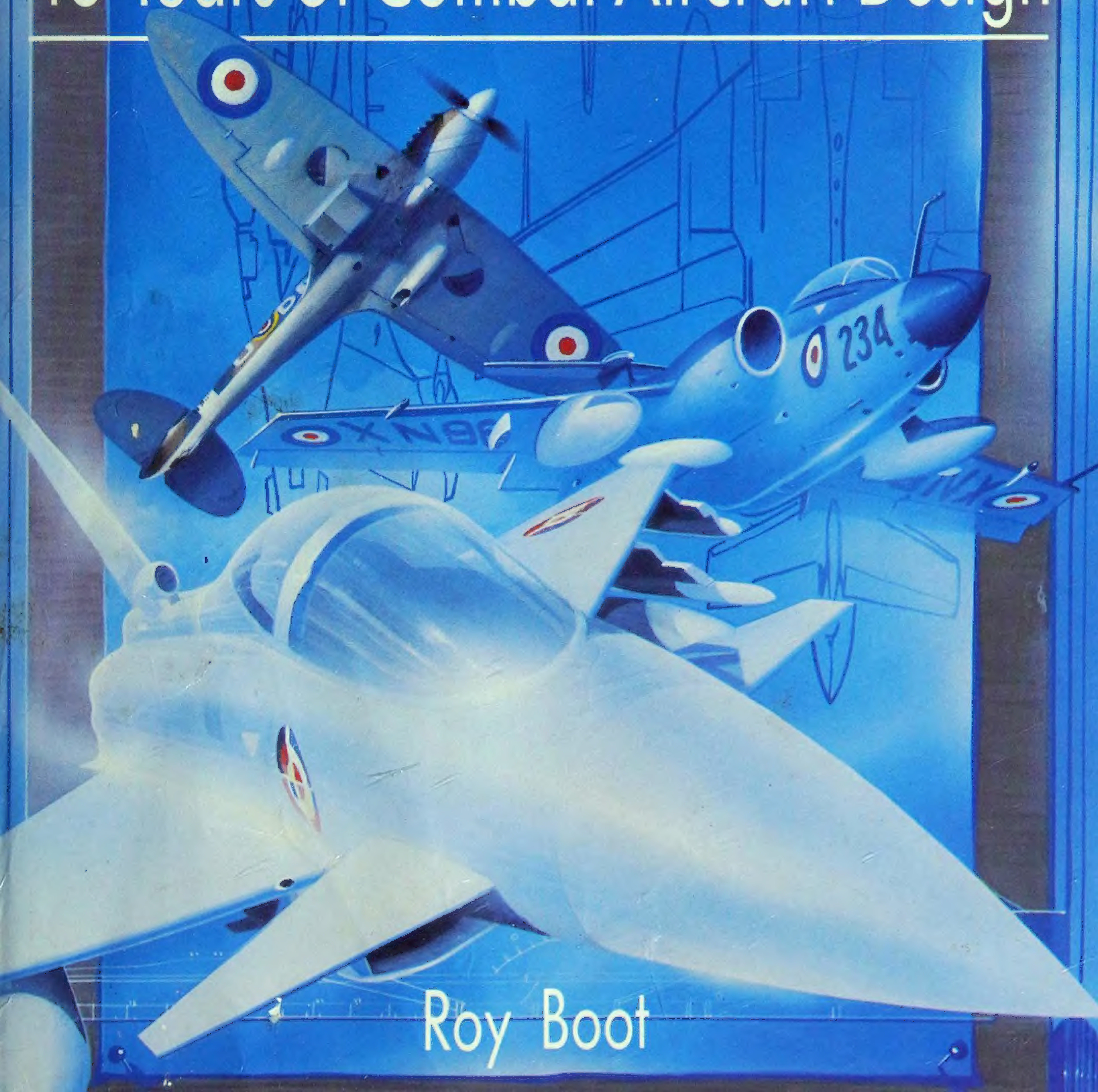
FROM SPITFIRE TO EUROFIGHTER

45 Years of Combat Aircraft Design



Roy Boot

From Spitfire to Eurofighter

Roy Boot is one of the most important figures in post-war aeronautical design, and the period he covers in this book is a long and varied one in the history of aviation. Beginning in 1941 with 'the unmistakable smell of dope and the cacophony of riveting and windy drill machines', it ends in the computer-assisted design offices and large corporations of today's aerospace industry.

Roy tells the story of the remarkable technological advances made in aircraft and weapon design during this period with great insight. From his early days as a student apprentice with Cunliffe Owen through to his time as Executive Director New Aircraft at British Aerospace, Warton, he describes the processes that gave rise to initial design concepts; he recounts how time and again even the best planned projects were held up by unforeseen and frustrating difficulties; and he tells of the ingenuity and patience by which he and his colleagues overcame the obstacles that beset them. He also gives interesting personal views on future aircraft design and procurement, making a valuable contribution to the debate which surrounds these complex subjects.

From Spitfire to Eurofighter contains a wealth of technical detail, and Roy reviews some sixty of the designs which passed through the Future Projects Office at Blackburn Aircraft during his period in charge. At the heart of the book lies what must surely be the pinnacle of the author's career — the Buccaneer project. This remarkably successful aircraft, which first saw service with the Royal Navy, is still operational today with the RAF, and its survival is a lasting compliment to Roy's skill as both engineer and manager.

Indeed, the whole book is a fitting testimonial to the author's lifetime of service to the British aircraft industry, and a fascinating record of one of the most exciting and volatile periods in aviation history.

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From Spitfire to Eurofighter

45 Years of Combat Aircraft Design

Roy Boot

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Finally, my thanks go to Roland (Bee) Beamont without whose encouragement the book might never have been started; to Bill Gunston, without whose support it might never have been finished; and also to Mike Edwards who in 1961 was emerging from an apprenticeship to become a flight test observer on the Buccaneer, and who then progressed to become Director and General Manager of British Aerospace, Brough. He was kind enough to monitor my writings throughout the preparation of the book to ensure that I did not exceed the bounds of industrial discretion.

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Foreword

The period which Roy Boot covers in this book is a long and varied one in the history of aviation. It begins in 1941 with 'the unmistakable smell of dope and the cacophony of riveting and windy drill machines' which characterized the many and diverse aircraft factories of those days. It ends in the computer-assisted design offices and large corporations of today's aerospace industry.

The remarkable technological advances of this period have had a significant impact on aircraft design and capability, not least in the field of military aviation. Today's Tornado GR.1, for example, allows the Royal Air Force to achieve with few aircraft, and small numbers of personnel, effects that during the Second World War would have needed a very large force of bombers and hundreds of aircrew with all the appropriate support.

Behind this dramatic increase in effectiveness lies over forty years of progress — sometimes painfully won — in aircraft and weapon design, and it is the story of those years that Roy Boot tells with such insight. He describes the processes and considerations that gave rise to initial design concepts; he recounts how time and again even the best planned projects were held up by unforeseen and frustrating difficulties; and he tells of the ingenuity and patience by which he and his colleagues overcame the obstacles that beset them, and of the ultimate satisfaction that rewarded their efforts. He also gives some interesting personal views on future aircraft design and procurement, thus making a valuable contribution to the debate which surrounds these complex subjects.

The book contains a wealth of technical detail, but, throughout his story, Roy never neglects the human dimension. We can always see — and identify with — the people behind the technology, be they engineers or pilots. Their one common facet, apart from their connection with aircraft, is the devotion and complete professionalism they bring to all their endeavours.

At the heart of the book, however, and surely the jewel in Roy Boot's crown, is the Buccaneer project. This remarkable success story produced an aircraft which first saw service with the Royal Navy over a quarter of a century ago, and which is still operational — albeit much modified and updated — with the Royal Air Force today. This fact alone is a significant tribute to the initial design concept and subsequent development work, and a lasting compliment to Roy's skill as both engineer and manager.

Indeed, the whole book is a fitting testimonial to the author's lifetime of service to the British aircraft industry. It is a valuable and fascinating record of one of the most exciting and volatile periods in aviation. It will be widely welcomed by aviation enthusiasts.

Marshal of the Royal Air Force
Sir David Craig GCB, OBE, AFC, MA, FRAeS, RAF

Introduction

In an author's signed copy of *Fighter Test Pilot* by Roland Beamont, Bee inscribed it 'Roy, we had a good forty years or so, didn't we?' I can't think of a better epitaph for my spell in the aircraft industry from 1941 to 1984.

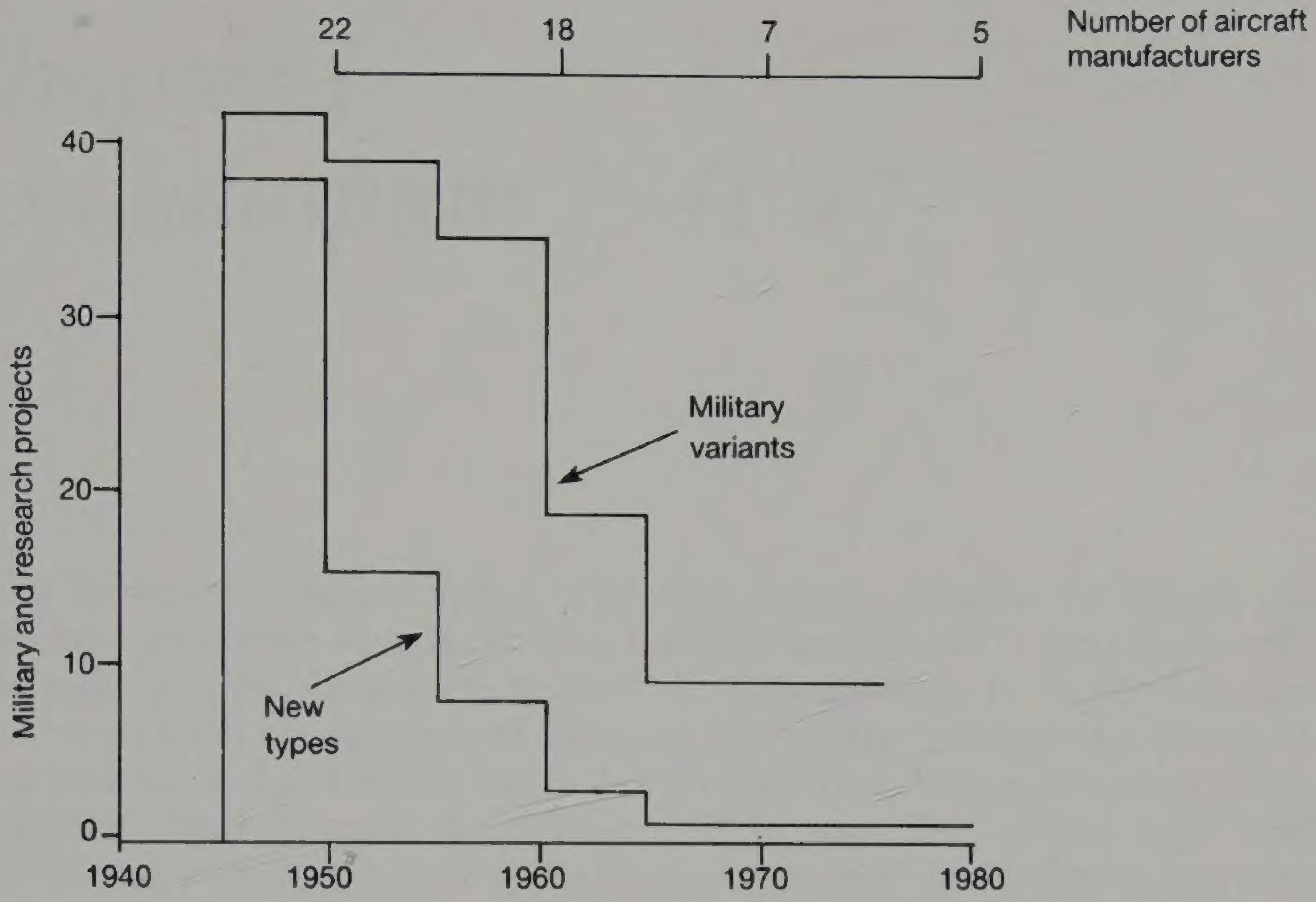
During that period the nature of the industry and its products has changed dramatically. From well over 20 individual firms capable of designing and producing major projects, it had reduced to just 3. Whereas in the immediate post-war era of 1945, taking combat aircraft alone, some 50 new types or major variants of older types were under development at any given time, the figure these days can be counted on the fingers of one hand. Time from initiation to first flight has increased typically from 20 to 50 months, and to first production from 50 to 100 months. There are exceptions, and at least the trend is for a reduction in this figures.

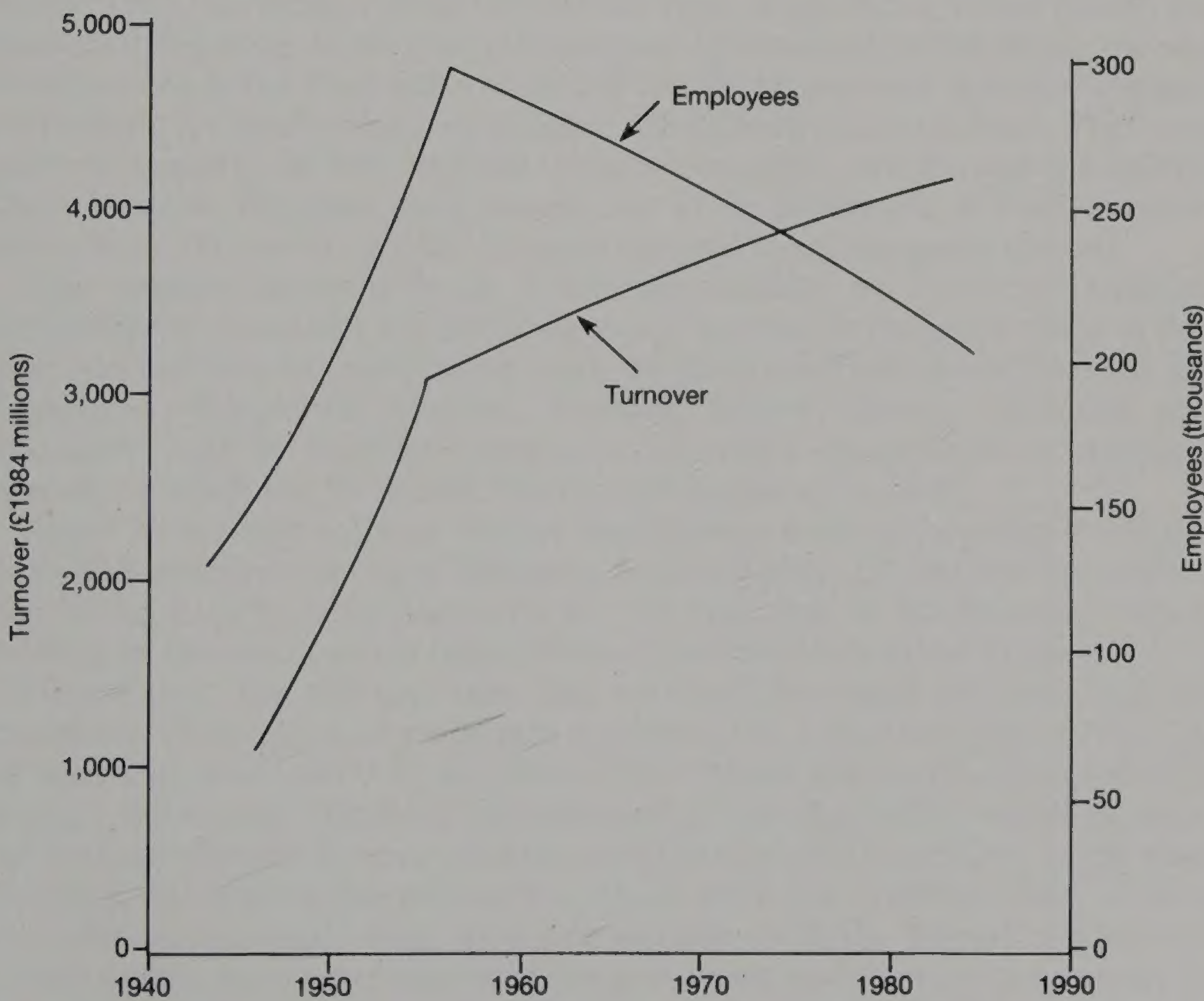
Again, concentrating on military combat aircraft, the unit cost in real terms is 25 times that of its World War Two equivalent. The cost of a single weapon load as a fraction of the cost of its carrying aircraft has also more than doubled, and with sophisticated stand-off air to ground weapons now emerging six-fold is more likely.

It is against this background of affordability of projects and the resources required to produce them that the shape of the industry has changed. Total employment has exceeded 200,000 in the past 30 years, and turnover in real terms has remained relatively constant. However, the days of scanning *Flight* and *Aeroplane* on a Friday seeking alternative employment, and the satisfaction of seeing on site the complete evolution of one's own project, are long since gone. Also, one's own career is more often in the hands of a large heirarchical organization, rather than along a series of steps of lucky personal initiative.

Nevertheless, the industry still demands, and fortunately gets, the dedication and resilience so often required in the smaller teams of yore. The job satisfaction is still there just as much, if patience and forebearance are practised on the necessary scale.

My sphere of activity, with the exception of three interesting and enjoyable years on the Airspeed Ambassador and on a few paper projects in the 1950s has been entirely on military aircraft, so I trust that the reader will accept this bias in my reminiscences.





The U.K. aircraft industry.

Chapter 1
Southampton 1941-44

One of the lessons learned during my career is that it helps to be slightly mad, and to have an infinite capacity to cope with the unexpected. I must have started in the right vein for, having made all of the arrangements to study Mechanical and Aeronautical Engineering at Glasgow University, through the offices of a friend I was invited to become the first of a student-apprentice scheme instituted by Cunliffe-Owen Aircraft at Southampton. In July 1941, at two days' notice and with both of my parents away on holiday, I packed up, left home and set off from Grimsby in the opposite direction to that originally planned.

In fact, Sir Hugo Cunliffe-Owen, a tobacco magnate, had set up the firm for the benefit of his aviation enthusiast son, anticipating a forthcoming aviation boom. They had made a small mark in the form of producing under licence the Burnelli flying wing. In the event the son was unfortunately killed during the war whilst serving in the Fleet Air Arm and of course the post-war industrial climate, particularly for small independent firms, was difficult to say the least. Their one post-war venture, the twin-engined ten-seat Concordia, saw the end of Cunliffe-Owen Aircraft, the plant being turned over to the production of Ford commercial vehicles. However, in 1941 I looked forward to the prospects offered.

The position involved being a full-time student at University College, Southampton, but when not attending there, working at the plant which at that time was involved in modification work on American-built aircraft such as the Tomahawk, Kittyhawk, Hudson, Ventura, Boston, Havoc, Baltimore and Marauder, with in addition construction of major components or complete aircraft, of which the Blenheim, Walrus and Seafire are typical.

Apart from short spells in various departments such as propeller overhaul, tool room machine shop and Blenheim final assembly, for the first two years I was in the Experimental Shop and for the final year in the Drawing Office, working in the main on trial installations of modifications to the Hudson.

Here I met for the first time the unmistakable smell of dope and the cacophony of riveting and windy drill machines. On a shop boy rate of 7½d (3p) an hour I worked from 7.30 am often until 7 pm six and sometimes seven days a week. With some difficulty I had managed to find digs in the Swaythling area, but having left home in some disarray, and short of vital equipment, some basic shopping was high on the priority list. There were two problems: first, to have time off when the shops were open, and secondly, with the 'blitzed' condition of Southampton, for a lot of shopping the population had to make the journey to Winchester. When the opportunity finally arrived I caught the train, but in my ignorance nearly met with disaster. I was familiar with the main-line station in

The Lockheed Hudson. *(12316/Flight)*

The Martin Baltimore. *(A4592/9)*

Winchester, but did not know that a rural Great Western line went up to Newbury via a subsidiary station in Winchester, Chesil St. There we stopped, and at the last minute I had a feeling of unease and checked with a fellow passenger and only just managed to jump off the train before it pulled out. Otherwise I would have been stranded in mid-country with a vital shopping expedition aborted. Later on, the practice of having every eighth day off was introduced at the factory, which made life very much easier for us solo exiles.

From the list of aircraft types and components in work in the factory it will be seen that there was a wide variety. The same was true of the inhabitants, many of whom had been drafted in from other walks of life. One memorable character with whom I worked was the rather lugubrious chargehand of the propeller section, who once when dismantling a Rotol propeller was thoroughly soused with oil under pressure. On all subsequent occasions he donned a full set of oilskins before commencing the operation, ignoring the ribaldry of all around him. The only exception to this was when he was working on the Curtis Electric propeller on the Tomahawk. I can have some sympathy with him, having suffered a not dissimilar misfortune when, with a hydraulic rig running on a Hudson, the union on the bodyside return line connection shook loose with the motor-driven pump running at full delivery. Like a pendulum the flexible metal delivery pipe swung backwards and forwards in an arc spraying DTD.585 fluid all over the place, and after a few swings with the pump still running came to rest with me in the direct line of fire. This was a major disaster with clothes rationing in force, for I was unable to wear those clothes again.

Mention of the Tomahawk above reminds me of a modification which was being fitted at the time which must have driven home to everyone the vital importance of detail design. A number of aircraft had been lost from the oil filler cap having come off in flight, with the result that the pilot was completely blinded. The modification was to overcome this problem.

One could find an infinite variety of people working in a wartime aircraft factory. One of the most surprising was in the toolroom machine shop, where, in what was almost exclusively a man's world, a fine-looking, strapping girl was to be seen operating the vitally important jig boring machine. She was Peggy Fowler, daughter of the Works Director. She was liked and respected by all, and must have been born with the inherent ability.

The situation in the Experimental Shop where I worked was equally surprising. There was not a single aircraft engineer among them, in what was supposed to be the élite of the factory workforce. Most had been through a quick wartime conversion course, and they included motor engineers, carpenters, and a leading dance-band saxophonist. The chargehand, Sid Lawton, was by profession an industrial chemist. He was a motorbike fanatic and highly skilled in all aspects of these machines. A Rudge Whitworth lover, he subsequently raced in the Isle of Man TT races, and ran a large motor-cycle business in Southampton. He was a most affable and imperturbable character, who guided the team smoothly through the undulating path of trial installation problems, and professional and personal upheavals among the crew.

The leading hand, Sid Bampton, was by trade a carpenter. With a lovely Hampshire accent and a cheerful personality, his skill at his new trade showed why he had been chosen for the job. Another who comes particularly to mind is

Gordon Freeman, a watchmaker by trade but probably the best fitter of them all.

The Experimental Hangar was adjacent to two landmarks. One was the Municipal Crematorium, whose operation sometimes necessitated the closing of the normally open hangar doors. The other was the compass-swinging base for the Eastleigh-built Spitfires. It was fascinating to see them pouring off the line, and occasionally to witness some of the flying by Jeffrey Quill and his team.

Some of the manoeuvres we witnessed were the prerogative of individual pilots. Occasionally, either for filming or a demonstration, a breathtaking sequence would take place. With the hangar doors open, work would temporarily stop. The high-speed outside loop with the bottom literally only feet from the ground was the most memorable — generally attributed to Alex Henshaw, although most of his Spitfire flying was from Castle Bromwich.

Another manoeuvre of some exuberance which I witnessed many times, the purpose of which escapes me, was, with the aircraft in the landing configuration and with an apparent alternating reversal of crossed controls, the Spitfire coming over in the manner of a demented corkscrew.

Of the many trial installations which we did, two seem worthy of recall. Fitting the first anti-submarine radar to the Hudson involved mounting large multi-element dipole aerials under the wings. These elements had to be welded onto a central stem with great accuracy. Heat distortion was a major problem, and initially only one person managed to devise a satisfactory technique — the watchmaker, Gordon Freeman. The tiny dimly lit cathode-ray tube in the cockpit which went with this installation must have taxed the operator to the limit, but the system was certainly a major step forward, and soon began to influence the war against the U-boat.

The second was an attempt to improve the Air-Sea Rescue operation. At this time rescue was by fast motor launch, or air-dropped rubber dinghies, or a somewhat hazardous landing on the sea by a Walrus amphibian followed by an even more hazardous take-off. The proposal was to use an airborne lifeboat parachuted down at the required spot. Part of the belly of the Hudson was cut away and an ordinary wooden ship's lifeboat tucked in. We could hardly believe our eyes as the Hudson staggered off across the grass, but it returned some time later minus lifeboat and everyone involved looked happy and a new era in Air-Sea Rescue was born. Over 40 years later, John Stamper related to me a conversation he had had with the parachute supplier when he was in charge of the heavy dropping programme on the Beverley. The story went that on release from the bomb bay the lifeboat rose up over the fuselage and disappeared between the two fins. I find it difficult to believe that the parachute gear would have worked under such conditions but that is the story as told and certainly many 'highly successful' first flights have contained elements such as this.

Eventually I graduated to the Drawing Office, being given the responsibility appropriate to my rawness for modification design on the Hudson and the later but similar Ventura. Apart from becoming for the first time indoctrinated in the mysteries of the SIS system (Standard Instruction Sheets for the installation of standard equipment), I learned the hard way the importance of digging out the last vestige of information on the area of the aircraft affected by the modification in hand.

The highlight of the week in the office in those days occurred at 4.55 on Friday

afternoons when, having been paid, we had a sweepstake on the number of the *Lord Nelson* class engine pulling the 3.20 from Waterloo to Bournemouth which flashed through our vista at the time when we were packing up. The office afforded an excellent view of both railway and road which ran into Southampton. This enabled us to watch the incessant stream of military traffic which passed by at the time of what we subsequently learned was the Dieppe Raid, although the guesswork which went on is best forgotten.

Meantime studies for a degree were going on. The life of a university student in wartime was far removed from the popular image. Courses were compressed and the authorities holding the threat of dereservation over one's head used it, at least where I was, to exert a heavy hand over one's comings and goings. In 1942 I was unexpectedly and unjustifiably caught up in the web. Looking back what happened seems hilarious, but at the time it was far from so.

It was a condition laid down by the authorities that one had to belong to a college-based semi-military organization. In most cases this was the Senior Training Corps, developed from the pre-war voluntary Officers Training Corps. This body would, when necessary, operate with the Home Guard, which we actually did on manoeuvres.

As I was committed to working in the factory during the college vacation periods, I was formally excused annual camp and therefore could not qualify for the standard certificates of proficiency — Certs A & B. For some reason the Adjutant saw fit to submit an adverse report on me because of this, although it was he who had granted me the exemption. This saw me carpeted in front of the Principal to no small tune, and threatened with immediate dereservation unless I drastically mended my ways. At this time there were still two years to go before I completed my degree course and I could see no clear way round the impasse. I therefore applied to join the alternative organization, the University Air Squadron. This involved volunteering for aircrew duties with posting at the end of the academic year and an indefinite interruption to my course. I duly became 1850479 AC.2 Boot, R.D., and placed on deferred service with the University Air Squadron and within six months had passed the Initial Training Wing Course. However, there was an automatic annual review of each individual's reservation by a joint University-Ministry of Labour and National Service body, somewhat misnamed the Joint Recruiting Board. Just as I was about to depart for full-time RAF training, my case came up for its annual review and my unilateral action was discovered, strongly disapproved of and steps set in motion to obtain my discharge from the Royal Air Force and to restore the status quo. My Discharge duly arrived, dated May 1943, endorsed 'Services no longer required, at own request'. I had never said a word, but such are the limitations of stereotyped Service jargon.

I then settled peacefully to complete my course and, as an exception, was allowed to continue in the University Air Squadron for a second year. Peace, however, was not to last for long. In the post arrived forms for a technical commission in the Royal Air Force, so assuming that someone had again chosen to alter my understood destiny I innocently filled in the forms and sent them back. At this time I was back in the factory and mentioned the matter to my employer. He looked apoplectic, and rushed off to get the whole thing cancelled. Once more I thought things had stabilized, but not so. As a result of my discharge from the Royal Air Force I was in due course required to re-register

for National Service. The official at the Labour Exchange who conducted this formality knew of my circumstances and said that there seemed no point in entering a preference for Service on the forms, with which I agreed. Imagine my surprise when a few weeks later I received the standard summons to attend a routine medical for the Army. I knew that once one had passed this point in the procedure the call-up process was irreversible so something had to be done quickly. An approach to the Secretary of the Joint Recruiting Board seemed to be the best bet but there were two problems: one, I was working in the factory and, secondly, I knew that the lady concerned worked in the Women's Section at the Labour Exchange. Eventually, with time off, I cycled down to the Labour Exchange and endeavoured to penetrate the Women's Section Entrance — no small feat I can assure you, for I was obstructed and redirected at every turn. When I finally did reach the splendid Miss Jordan, she had the whole thing settled within minutes and I could really settle down to complete my course.

The path however continued to be undulating. Part I Finals taken at the end of my second year found me with extensive and painful blisters up to the full length of the inside arms. Not a happy state in which to sit a prolonged written examination. In fact I was one of only about four from a class of over 30 to pass completely, many being referred for a resit in one subject.

Having finished the papers, I caught the first train north for home and displayed my source of discomfort to my father. He took one look and said, 'It sounds ridiculous but it looks like mustard gas to me'. As I had also had gas training, I immediately recognised the wisdom of his words and off to the doctor I went.

With my by now well-developed ability for appalling mistiming, it transpired that the area had just suffered from an attack with phosphorus bombs and doctors had been instructed to refer any burn type injuries to the Public Health Authority, so there I had to go. It was rapidly established that the blisters were due either to mustard gas or to the similar Lewisite which however contains arsenic, in the event of which the fluid should be extracted from the blisters with a hypodermic needle. Now I did not have the classic large blisters of the text books for a concentrated attack, but hundreds of tiny ones. In any event it was too good an opportunity to be missed with a real gas casualty, so everyone who could be rounded up was summoned to examine the mess and witness the proceedings, while I held up each arm in turn and each blister was dealt with. On completion, both arms were so heavily dressed and bandaged that they became completely stiff from wrist to armpit. I could neither dress, wash nor shave myself for a week. Eating consisted of getting a morsel of food on to a fork or spoon, contorting my wrist in the general direction of the mouth and making a determined move from the neck in the hope of making contact.

How I got the pernicious contamination remains a mystery, but I had on the Sunday before the examination, in scorching heat, abandoned an attempt to reach Stonehenge by bicycle to bask in the sunshine in a field by the roadside. With Boscombe Down airfield and Porton Chemical Warfare Establishment nearby, and countless army manoeuvres taking place in the area, the cause remains obscure, but the indications are that the tips of the blades of grass could have been contaminated. Recovery was quick, then back to Southampton for a spell in the Drawing Office, and then back to college for the final year.

The Part 2 syllabus in peacetime normally ran for two years but now had to be

covered in one. Unfortunately illness of two of the four principal lecturers was such that we did not commence their courses until the end of the first term. The University of London had just innovated a second finals examination in December, so the three of us on my particular course applied for an extension of our reservations to take advantage of this. It was granted to the other two but, because of conditions apparently laid down when I was discharged from the Royal Air Force, I was refused and had to do the best that I could.

In taking the finals I felt that everything had gone reasonably well until the last paper — Aircraft Structures. Based on the pattern of past papers we had been drilled with differential equation magic and Howard polar diagrams. The paper that faced me, I now know, would have been meat and gravy to a practising stressman but at the time it was largely gobbledygook to me, and I was sure that I had failed. In fact I had passed, but it must have been only just, and it pulled down my overall marks such that I did not get the grade of degree which had been predicted and of which I had felt reasonably confident. This did prove to be a drawback for permanent service in Government establishments, but did not affect one's prospects in industry.

On completion of the course, like everyone else, I was required to present myself at the Ministry of Aircraft Production headquarters to be interviewed by Mr Snow and Major Walters for allocation in the National Interest. There was to be no going back to Cunliffe-Owen for me, nor to either of the major aircraft firms in which I had expressed interest. I was to join the staff of the Ministry at its headquarters in Millbank, London SW1.

The Douglas Boston III. *(A4592/7)*

Chapter 2
Ministry of Aircraft Production

As a result of my initial interview I was seen by Captain R. N. 'Loopy' Liptrot, who seized on someone with an aeronautical degree and practical experience for his department, then known as RDT 1.

The department was divided into sections primarily responsible for a particular class of aircraft, with three main functions:

a) Routine performance data on in-service aircraft with, where necessary, direct liaison with operational units.
b) Forward looking to recommend the nature of future projects and the assessment of projects put forward by industry, either in response to a requirement or as a private venture.
c) To advise the Director of Technical Development (then Mr N. E. 'Nero' Rowe) on the merit of proposals put forward by inventors.

Once again I joined an interesting collection of people brought together in this environment by the war. The Section heads were all permanent civil servants of pre-war origin. Nearly everyone else was a wartime temporary and the staff included mathematicians, civil engineers, physicists, college lecturers and a biologist — just two of us were professional aeronautical engineers — backed up of course by the usual administrative and clerical support, most of whom were also wartime temporaries.

Working conditions were good, there was an excellent *esprit de corps*, and some of our energies were spent in conflict with bureaucratic, but thankfully remote, administrators. In spite of the variety of qualifications, the tasks in hand were addressed in a skilled and expeditious way.

It was my experience, both during my spell at the Ministry and also during time spent in industry that, whilst the so-called specialist branches can be pedantic and obstructive to genuine progress, the project-oriented branches are highly motivated and efficient.

I must have landed one of the plum jobs, for I found myself in a small office headed by Handel Davies, a remarkable man and a delight to be with, and from whom I learned a lot for the future. The section was responsible for fighters and other high-speed aircraft. This had encompassed all the piston-engined fighters but, with the advent of jet propulsion and compressibility problems, and later sweepback, we were for a time regarded as the experts on all such applications.

We each carried responsibility for specific current types. Included in mine were the Spitfire, Mustang, Thunderbolt and Mosquito, and later the Meteor and Vampire. We worked very closely with the corresponding airframe branch, known as RDL.

The Spitfire I. *(A4591/8)*

The Spitfire F21. *(A4591/5)*

With the in-service types, things on the whole worked smoothly to a routine, although a permanent problem was trying to persuade the squadrons to cruise at low revs and high boost — they seemed instinctively to keep the revs up and the boost low, with a markedly adverse effect on range.

One or two high spots from this period stand out. German fighters suddenly showed a sharp increase in performance. By the calculation of various possibilities we deduced that an anti-detonant was being used in the engine, and set about doing likewise to counter it. It subsequently transpired that the Germans were using alcohol, and later nitrous oxide, but our solution was methanol water. Rolls-Royce, for good reasons, were reluctant to use it on the Merlin, although Packard in the United States had no such inhibitions and used it for the Merlins produced in their plant, many of which were fitted to Mustangs. Much later on, some British Merlins and Griffons did use the method.

Another high spot arose during a spell of low-level air combat in North Africa, where the Fw 190 outperformed the Spitfire V. Much of the development of the Merlin had been on improved supercharging to improve high-altitude performance. Two-speed, and later two-stage, superchargers were introduced. An enterprising engineer officer out in the battle zone decided that potential performance at the low levels then relevant was being wasted as a result of the power being absorbed by the supercharger to no useful purpose, and thought that the power should be diverted to the propeller. To change the supercharger gearing would be a very protracted matter but to crop the diameter of the impeller would be as effective, and much more expeditious. He therefore despatched a signal suggesting this course of action. This duly passed through the relevant branches of the Ministry, who all thought that it was a very good idea. The appropriate parts were ordered and a signal sent off to the proposer adopting his idea and giving the delivery dates for the modified parts, which of course was many months ahead. We subsequently learned that he did not wait for this but did the work in the field. This involved cropping the impeller diameter from 10.5 to 9.25 inches on a component which revolved at some 28,000 rpm and which therefore had to be very finely balanced. How this was done out in the field remains a mystery, but it is people like that who win wars. At least he can claim to have produced the prototypes of the 45M derivative of the Merlin 45.

On another occasion a rather marginal ferry flight was being planned for the delivery of some Mosquitos to the Soviet Union. Range calculations involved calculating the power required from the engine and then reading off the specific fuel consumption from the curves and multiplying up to obtain the fuel consumption. Fighters at this time were almost exclusively single-engined. On the rare occasions when a multi-engined type was being dealt with it was very easy when, having determined the fuel consumption of the engine in the manner described, to forget to multiply the result by the number of engines. This unfortunately happened in this case (no, fortunately I was not the culprit) and the mission was declared to be quite safe. The error was discovered by the Russians, who were convinced that it was deliberate sabotage and a major incident was blowing up. The meeting to settle the dispute was the province of a branch of the Air Ministry specializing in such affairs. Handel attended this meeting and, arriving early, got into conversation with the Chairman-to-be. He was bemoaning the posting of his assistant, and the trouble that this was causing

The Mosquito B.IV. *(A4592/1)*

The Mosquito F.II. *(A4592/3)*

him, made worse by the news which he had just received of the name of his replacement. 'This branch has a serious job to do, and is no place for comedians.' What price the famed radio show *Much Binding in the Marsh*, for the issue was settled by the sheer competence of the Wing Commander in the chair, whose personality was later to become a national source of delight. There are no prizes for guessing his name — Kenneth Horne — nor that of his incoming assistant.

Another recollection of my early days in the office concerned a visit by Dick Clarkson of de Havilland Aircraft. A lot of effort had gone into the development of the E.6/41 Spider Crab, later renamed Vampire, which with its 3,000 lb thrust Goblin and top speed of 530 mph was being prepared to enter service. The words 'We have redesigned the Vampire, you know' were followed by the unfurling of drawings and data which, as I remember, were received by the establishment with absolute horror for rocking the boat at the wrong time.

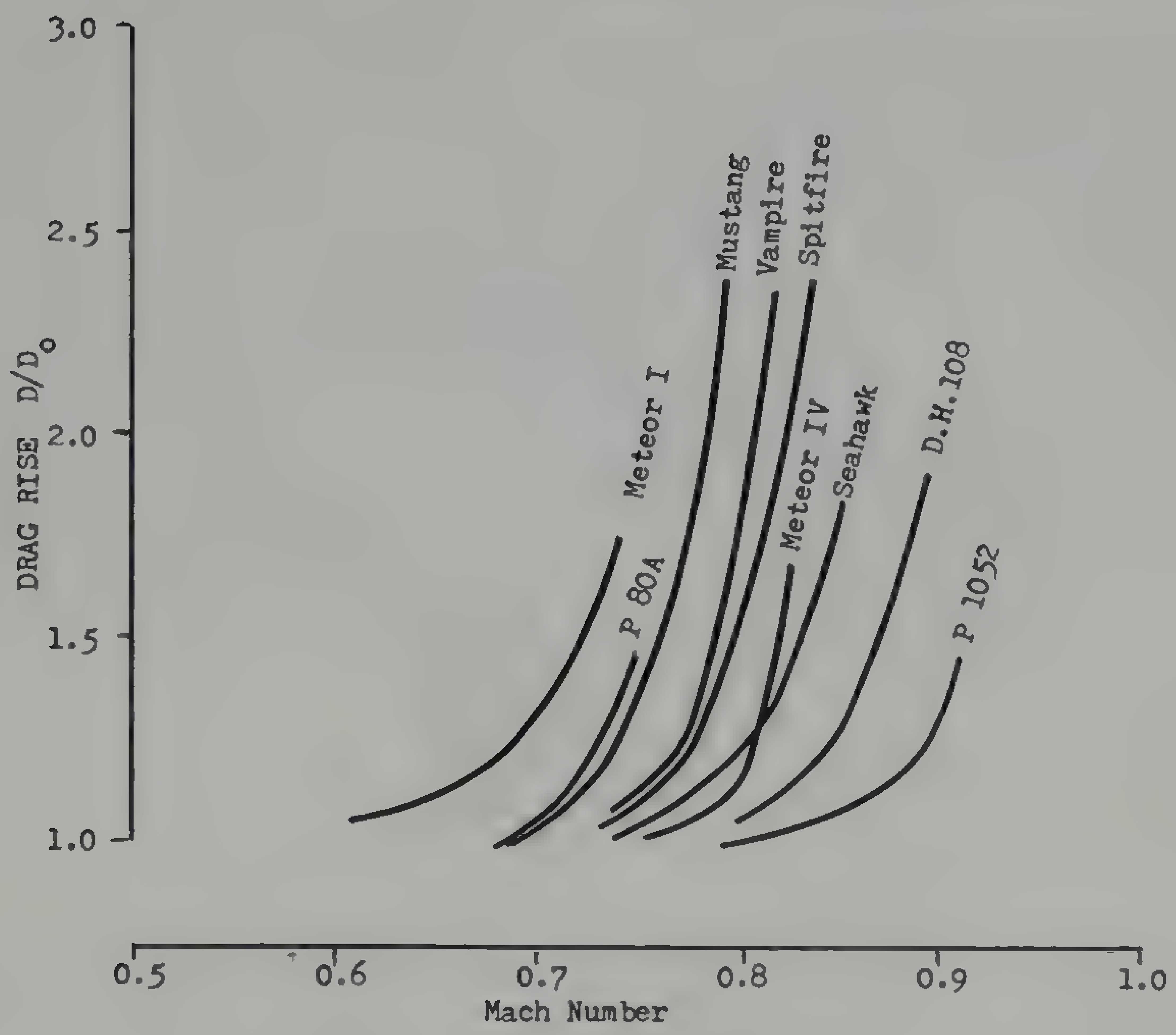
When some five years later the Venom was unveiled with a 100 mph increase in top speed it sounded very reminiscent of the discarded Clarkson proposals of 1944. These would have produced the higher performance much earlier, but, as things turned out, too late to be used in the war.

One found with inventors that the more outrageous were their proposals the more persistent they became. This was at times embarrassing, as we could not afford to discard a good idea. In the end we developed a procedure which after a reasonable time caused the interviewer to depart in haste as a result of a simulated signal from above, thereby bringing the proceedings to an end. This is not quite in the class of the unsubstantiated rumour that, when he was the Minister in critical days, Lord Beaverbrook kept two senior officials on call to be dressed down in the presence of a senior complainant who then went away satisfied. It was alleged to be based on the theory that no such individual would pay more than two such visits. I cannot answer for the veracity of the story but it certainly fits the legend.

Flight into regions of compressibility effects had become a regular feature of our daily activities. Piston-engined fighter speeds had leaped by some 100 mph, and jet propulsion was coming in to extend this even further. One unexpected encounter with compressibility arose with the Westland Welkin, designed to Specification F.7/41 to intercept high-flying bombers. It first flew in 1942. With its high aspect ratio 70 ft-span wing, to give structural integrity the root thickness/chord ratio had been made about 19 per cent. At the high altitude for which it was designed the wing characteristics incurred compressibility effects at quite modest speeds, which severely reduced the combat capability.

Apart from stability and control problems, which had to be understood and overcome, performance prediction methods had to be developed for next-generation projects. We were particularly concerned with drag-rise data. Initially, these were derived from dive tests on such types as the Spitfire, Mustang and Thunderbolt. With major uncertainties on propeller efficiency and engine exhaust ejector thrust, the latter giving up to some 150 horsepower, the analysis could be inaccurate. It is worth recalling that during this period a Spitfire was dived to a Mach Number of 0.92. Subsequently simple thrust-measuring systems were fitted to the early jet-propelled prototypes, and more reliable data obtained.

Typical drag-rise curves deduced are illustrated, from which it became



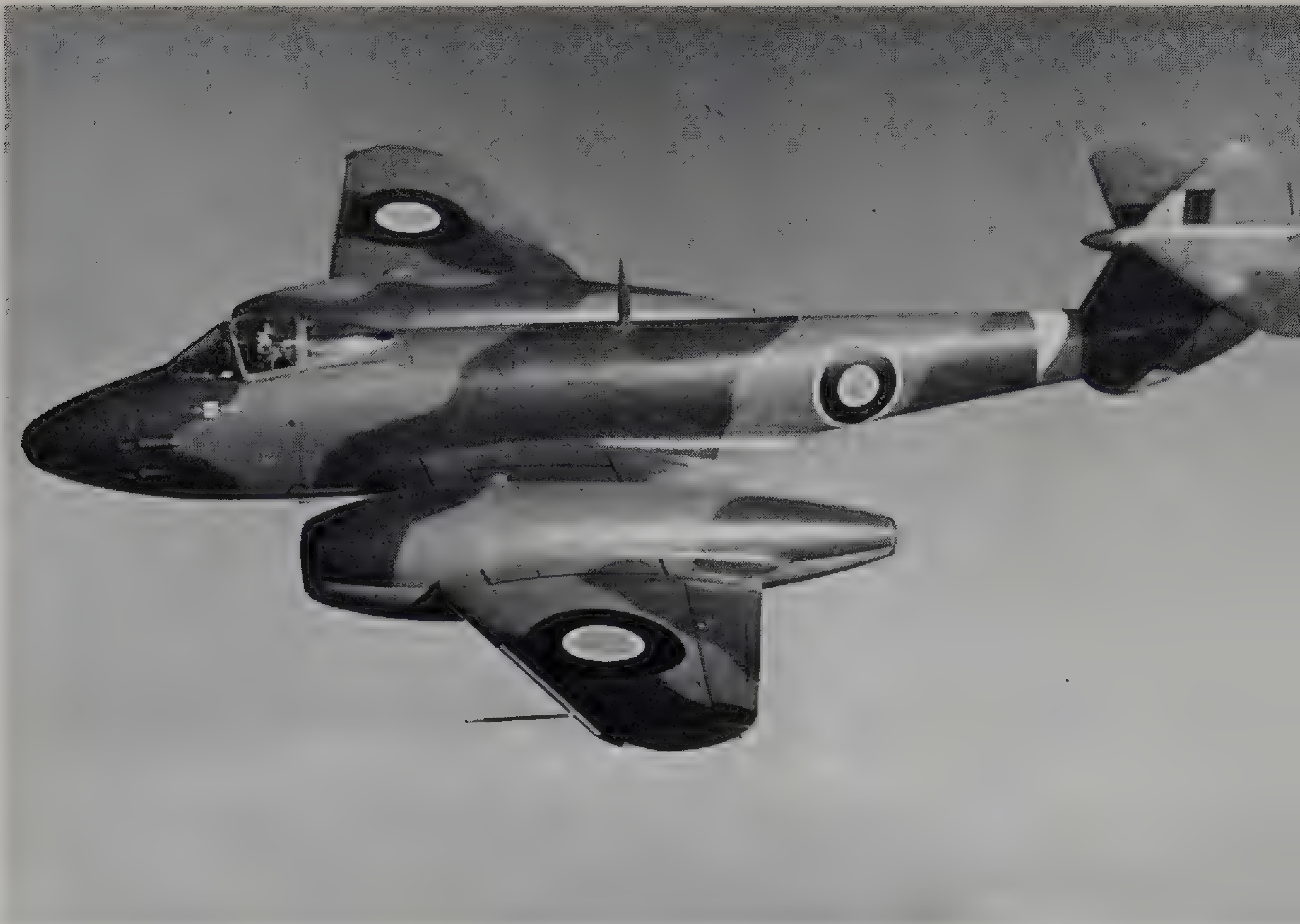
Early compressibility drag data.

apparent that, other things being equal (which was by no means always the case), a near-standard drag-rise curve applied with the onset directly related to the wing thickness/chord ratio although for this a certain degree of aerodynamic cleanliness was essential. Exceptions worth mentioning include the rather cumbersome Thunderbolt and the original Meteor with short nacelles which were subsequently extended fore and aft.

We felt that we had a predictive method for the next generation which included the E.10/44, E.1/44 and the Hawker P.1040.

In mid-1945 data on the potential of sweepback started emerging from Germany, with masses of wind-tunnel results and rather disturbing news of some of the projects which they then had in hand, such as the Messerschmitt P 1101 illustrated. All of this was studied extensively, and Handel and I wrote a number of papers on possible configurations for future interceptor fighters using the more modern axial-flow jet engines, basing the characteristics on scaled versions of the Rolls-Royce AJ. 65, later named the Avon. We favoured a single-engined configuration rather than a twin with nacelles, and felt that sweepback was overall beneficial in spite of giving a lower climb performance and with the possibility of some manoeuvring problems. The establishment rejected the idea of the application of sweepback on the grounds of 'insufficient evidence'. The Americans unhesitatingly applied sweepback to their then-unswept F-84 and F-86 projects, to the great disadvantage of the United Kingdom in the post-war market and Korean war, when we had no modern fighter.

In order to obtain a satisfactory level of manoeuvrability we assumed a wing loading at combat weight of 40 lb/sq ft for unswept wings and 35 lb/sq ft for swept-wing configurations. These figures can be compared with values which we would use today, with an even greater level of manoeuvrability of 70 and



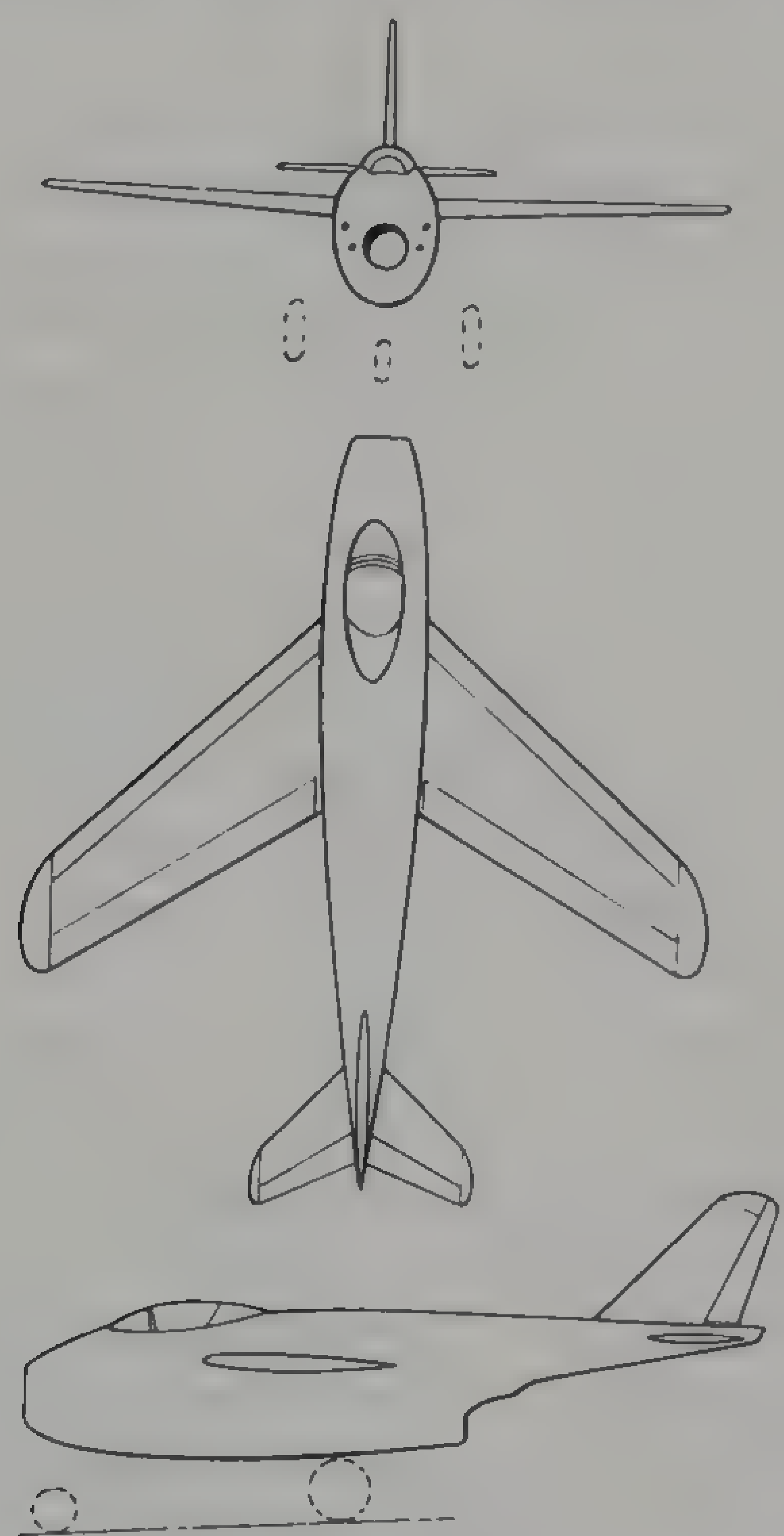
The Meteor F.IV. *(A4591/4)*

The Vampire FB.5. *(A4592/3)*

60 lb/sq ft respectively. Such have been the advances in wing design and combat manoeuvre devices.

The data on sweepback extracted from Germany showed that, whilst two-dimensional flow theory suggested that the effective Mach Number over the wing was the true Mach Number multiplied by the cosine of the angle of sweepback of the wing quarter-chord line, three-dimensional flow effects reduced the gain and a purely empirical law was deduced reducing the effect to the square root of the cosine.

At least this empirical law held good at the aspect ratios then current on fighter aircraft, as can be seen on the diagram comparing the drag-rise curves on the Vampire and de Havilland 108 and on the Hawker P.1040 and P.1052. Some years later J. R. Collingbourne of the RAE produced a paper giving a predictive



The Messerschmitt P 1101 — general arrangement.

method for calculating the Mach Number for the start of the drag rise for a wide range of sweepback angles and aspect ratios. I subsequently extended it to produce a method for predicting the complete subsonic drag-rise curve, and this was used extensively until it was overtaken by modern complex computer methods.

Whilst in 1944/1945 the fastest piston-engined fighters were just entering the zone of compressibility effects, it was the advent of jet-propelled fighters that brought the subject truly to the forefront. The Gloster E.28/39 and Meteor produced much of the data, although these were subsequently augmented by the de Havilland Vampire with the Goblin engine.

The pace of development of the Meteor was accelerated by the remarkable progress made at Rolls-Royce when they at last took over from Rover development of the jet engines which the latter had inherited from Sir Frank Whittle

and his Power Jets team. A detailed account of the work is given in the Airlife books *Whittle — the True Story* and *Not Much of an Engineer.*

The W.2B/23 Welland, a Whittle design inherited from Rover, flew at a rating of 1,400 lb thrust in the E.28/39 in March 1943 and in an F.9/40 Meteor in June 1943. It was put into limited production in October 1943, to be delivered with a thrust of 1,600 lb from May 1944 for the production Meteor I.

Refinements to the design led to the RB.37 Derwent I, which ran in June 1943, and was type tested at 2,000 lb in October 1943 following the start of design in April of that year. Production started in mid-1944 to give the engines which powered the quantity built Meteor III. Further developments were the Derwent II run in June 1944 at 2,200 lb, and the Derwent IV run in February 1945 at 2,400 lb thrust. These latter engines were scheduled to improve Meteor performance, then in the 450-500 mph range, with the Vampire later coming into service with a speed of 530 mph.

It may occur to the reader that by today's standards the short time intervals recorded in these programmes were incredible, but far more was to follow. In May 1944 Rolls-Royce started to design an enlarged but improved Derwent targeted for 4,000-5,000 lb. It first ran in October 1944, and passed type tests at 4,000 lb in January 1945 and at 5,000 lb in November 1945.

Such was the outstanding success of this engine that a scaled-down version was proposed which could be fitted to the Meteor. Design of the Derwent V began in January 1945, it ran in June and after type test at 3,500 lb it first flew in a Meteor in August 1945. This engine weighed only 15 per cent more than the original 1,600 lb Welland, but gave the Meteor a top speed of 580 mph, as good as or better than some of its intended successors, and of course paved the way for the successful attempts on the world speed record.

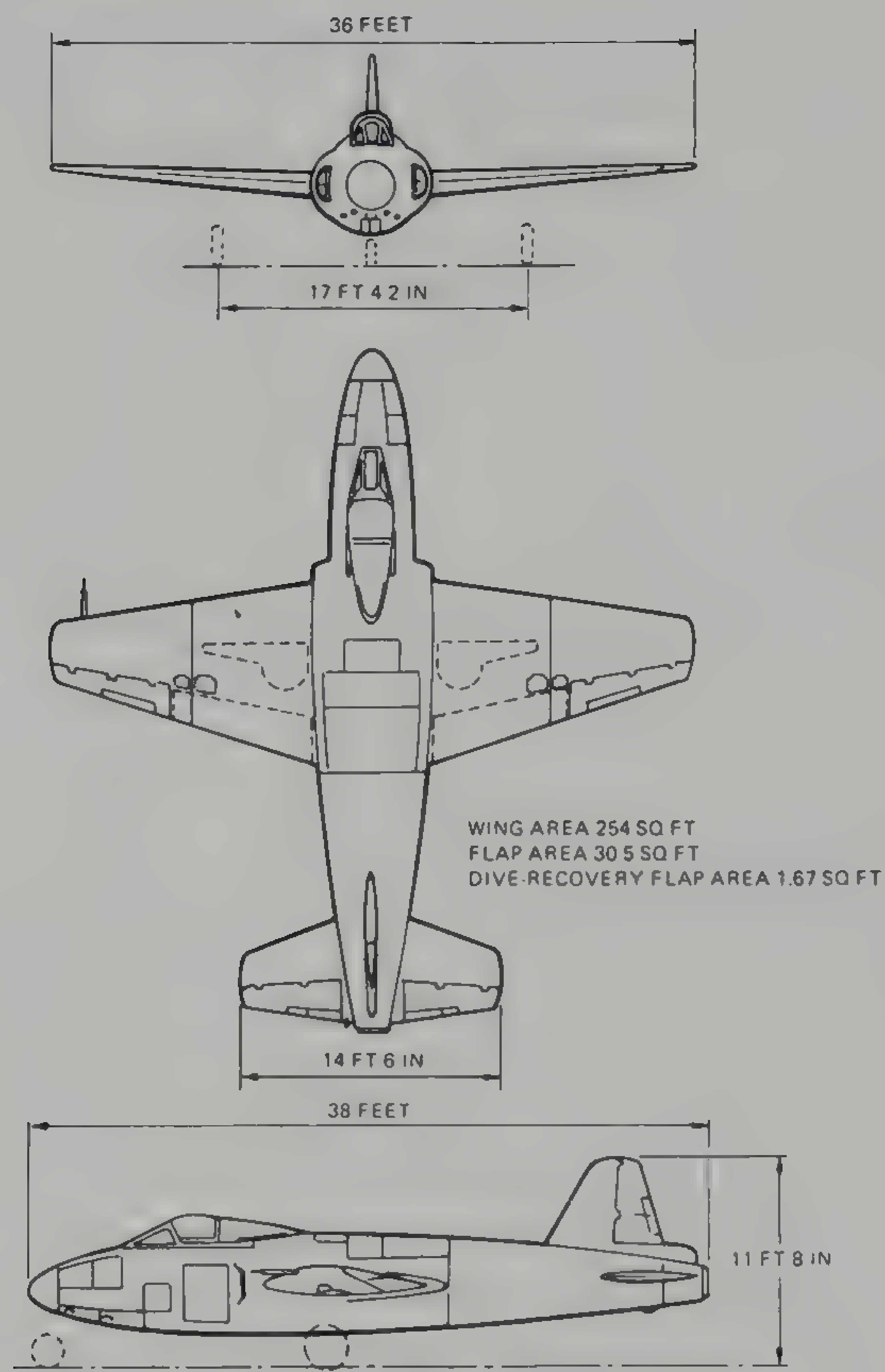
At this stage we were asked to produce a data sheet for use at the highest levels on the performance of all known British and foreign jet-propelled fighters. The result was a large multi-column sheet of paper listing the main performance parameters. With several stages of engine development applicable at that time to the Meteor and Vampire, I compiled a separate column for each stage, with footnotes defining timing and status. On handing it over to Handel for approval, he looked at it, laughed, and said, 'It looks just like a railway timetable to me'. I asked him to give it back to me and altered two of the Meteor footnotes to 'Saturdays only' and 'Saturdays excepted'. We all had a laugh, and filed it away until it was sent for. After some weeks this happened in a panic, when we snatched it out of the drawer and sent it on its way. Later on I remembered what I had done, and asked Handel if he remembered the incident (which he did), but when I asked him if he had ever altered it back he said, 'No, didn't You?' to which I had to reply in the negative. We sweated it out in some trepidation, but never heard a thing. We shall never know whether the high-ups didn't look at it or, if they did, they either believed what it said or like us had a good laugh at a time when one was very welcome.

Another of the technical posers which arose during these early days of jet propulsion was when the measured speed versus altitude curves crossed over the predicted values. At that time there were no altitude test chambers, and the predicted engine curves were based on unsubstantiated theory, so there was a certain amount of dismay that the theory could be wrong. Thinking about it I had an idea which I put to the test. As it seemed to give the right results, I wrote

a short note on the subject in December 1945 which caused quite a few eyebrows to be raised in disbelief, but which has stood the test of time. An extract from that note reads:

> 'Hitherto it has been the practice to calculate the profile drag of an aircraft for the Reynolds Number corresponding to the maximum level speed at the rated altitude, and to use this value for all conditions. This has always given satisfactory results, as the profile drag of the wings, fuselage and tail has been a relatively small proportion of the total drag; the remainder being composed of the cooling, interference, external projections and gaps, etc. The inaccuracies of estimation of airscrew efficiency, ejector thrust, etc, outweighed the refinements in drag analysis which calculations of change of drag with Reynolds Number would have involved in performance prediction.
>
> 'The position on new high-speed jet-propelled aircraft is rather different. The aircraft are much cleaner, with better surface finish and the proportion of the total profile drag of the wings, fuselage, tail, etc, which may be expected to vary with Reynolds Number is much greater. Thus if the theoretical variation in drag be applied, the effect on estimated performance would be far greater than with the former reciprocating-engined aircraft.
>
> 'To date, the practice of using a constant profile drag has been continued, one argument put forward in its favour being that the theoretical increase in basic drag associated with increasing altitude would tend to be offset by a decrease in drag due to surface roughness effect.
>
> 'The first evidence to discount this occurred in a complete analysis of Meteor flight tests in March 1945, when the speed curves repeatedly crossed the predicted curves. There were indications that, subject to the engines giving the specified thrust, the drag varied with Reynolds Number in exact accordance with theory, but as there was no guarantee as to the actual value of engine thrust obtained, the evidence was not conclusive but could be considered indicative.
>
> 'More recently, flight tests have been carried out on production Vampires with standardized engines of various ratings. The thrust in flight of these engines has been measured and so is known. They agree very well with the specified thrust. Once again, the drag appeared to vary with Reynolds Number exactly as would be predicted.
>
> 'The evidence was now much stronger, but to confirm it other possible factors were investigated, viz, variation with Reynolds Number of drag due to surface roughness and any change in transition with Reynolds Number due to surface roughness. From this it became apparent that the variation of aircraft drag as deduced from flight tests does not appear to be affected by surface roughness or change in transition, and can be totally explained by the theoretical Reynolds Number effect on the profile drag of wings, fuselage, tail, etc, and it is suggested that this correction be applied in future.'

One way and another, the pressure of work was fairly taxing, and sanity had to be retained by the occasional outburst of humour. One such springs particularly to mind. It was the practice for any new project or proposal for a file



The Gloster E1/44 — general arrangement.

to be opened in a branch of the Air Ministry, and for this to be circulated on a standard route to collect comments and assessments prior to final consideration. Some wag in the originating branch drew up a project proposal which must have owed its ancestry to a combination of Emmett and Noel Pemberton-Billing, and he wrote in Edward Lear nonsense style a parody of his normal comments with a strong element of self-Mickey-taking. He named it *Circulambumbating File No 1* and sent it on its way. Everyone on the circulation path entered into the spirit and wrote his piece. We were near the end of the path, enjoyed reading what had been written and passed it on. I have often wondered what became of it; it was worth preserving.

Based on the Nene engine, the major step beyond the Meteor and Vampire was planned to be the Gloster E.1/44 (33 per cent heavier and 100 mph faster than the Vampire) with the Supermarine E.10/44 with the Spiteful wing as an interim type. In the event, the first prototype of the E.1/44 was terminally damaged colliding with a lampost on its way to the airfield! The second prototype eventually flew, but the performance of this unswept aircraft was not sufficiently ahead of what was being achieved by the Meteor, and the project was abandoned. Also, the E.10/44 never entered service with the Royal Air Force, but a Naval derivative, the E1/45, as the Attacker, served the Royal Navy well for many years.

In the early days of jet engines in this country the complex axial-flow compressor was rejected in favour of the centrifugal type with a pressure ratio of

about 4.5. There were two fundamentally different solutions to this. One, as developed by Whittle, had a two-sided impeller which drew air from a surrounding plenum chamber. This required a low speed aircraft intake with a velocity ratio of about 0.3 and a gentle duct expansion into the plenum chamber. The other, favoured by Major Frank Halford of de Havilland, was the single-sided impeller with the air directed straight into the eye of the impeller and compatible with a smaller high-speed intake with a velocity ratio of around 0.5. This allowed the neat wing root intakes of the Vampire and Venom, which can be compared with the rather large fuselage side intakes on the E.1/44 and E.10/44.

One highly patriotic designer, (Camm), who refused to consider sweepback because it was of German origin, also considered the large fuselage side intakes to be a major source of disfigurement and called them 'Elephant's Ears'. He put forward an unsolicited proposal for a beautiful aircraft with neat wing-root intakes and fuselage lines improved by exhausting the jet through a bifurcated jetpipe emerging at the wing root trailing edge. The official reaction was that the intakes were hopelessly inefficient in conjunction with the Nene engine proposed, but that in any case the project offered little advantage over the already committed E.1/44 and E.10/44. However, in the papers that Handel and I had written we had shown a definite advantage for carrier-based interceptors to use a bifuel rocket to improve time to height. Camm's new configuration appealed to the Royal Navy, as it was fundamentally suited to a rocket installation in the tail. The shortcomings of the intake were cleverly solved by Dr John Seddon at the RAE, and the Navy placed an order for the type. The resultant Sea Hawk was a success, but without the rocket. The only time the type flew with a rocket installed in the tail was at Bitteswell, as the P.1072 flight development vehicle for the 2,000 lb thrust Armstrong Siddeley Snarler.

Another diversion from normal activities arose from a proposal to attempt to break the world speed record, taking advantage of the new jet propulsion and the capability of the Derwent V Meteor. Two problems were predominant. With the international rules requiring a low-level figure-of-eight course to be flown, was there sufficient fuel in the Meteor? The second concerned the handling at low level at the speeds which were anticipated. Resolution of the latter is well told in Bee's book, *Fighter Test Pilot*. The original sponsors of the attempt were the Engine Development Branch under Group Captain Watts.

Consideration subsequently came to our branch, and glory be, I discovered that complacency on fuel capacity which had persisted was due to the earlier classic mistake having been made — yes, the Meteor had *two* engines. However, having put the sums right, fuel capacity was found to be just adequate, subject to careful planning, and arrangements for the attempt went ahead.

A careful assessment was made of the speed likely to be obtained, and of the associated problems. We decided that a speed of around 600 mph was probable, with the best result likely to be reached on a cold day. The outcome is well known, 606 mph being attained by Group Captain 'Willie' Wilson over Herne Bay in Meteor IV EE 455 in the autumn of 1945.

Following airframe modifications and uprating of the engines a further attempt was planned over Lyme Bay. For this we predicted a speed of 615 mph, with the recommendation that the attempt be made on a warm day. Once more, the establishment questioned our competence or sanity, for had we not suggested a cold day for the previous attempt? The reasoning was based on the

fact that, whilst engine thrust decreases with increasing temperature, the speed of sound and hence the Mach Number for any given speed, is directly proportional to the square root of absolute temperature. For the first attempt, the expected speed would take us to just below the drag-rise point, so the more engine thrust the better. For the second attempt we expected to be round the bottom of the drag rise and increase in temperature would reduce the drag rise more than it would reduce the engine thrust. The record was successfully attacked by Group Captain Teddy Donaldson in Meteor EE 549 with a speed of 616 mph, and everyone was happy.

It is interesting to reflect on the extent of fighter development which took place during the period of the war, where we started with the 5,900 lb, 1030 hp, 360 mph Spitfire and the 6,500 lb, 330 mph Hurricane. The Merlin engine had a full-throttle height above which power falls off with increasing altitude of 16,000 ft.

The Hurricane was to progress from 1,030 hp to 1,620 hp with a 30 per cent increase in weight, but with little increase in top speed although much greater lethality, before being succeeded in 1942 by the Typhoon and later the Tempest family. These were in the 12,000 to 13,000 lb category. The Tempest V with its 2,180 hp Sabre had a top speed of 426 mph, and entered service in 1944, just in time and fast enough to play a major role in interception of the V.1 flying bomb. The 2,520 hp Centaurus-engined Tempest II and the 2,300 hp Sabre V-engined Tempest VI, both with a top speed of around 440 mph, did not see active service until just after the war, but they had been a significant part of the workload in our office. Following on from this was the Centaurus-engined F.12/43 Fury, with a top speed of 460 mph. With the higher performance now available from the jet-propelled types it did not go into production for the Royal Air Force, but the variant produced to Specification N.22/43 as the Sea Fury will be remembered with affection.

The evolution of the Spitfire must be rated as remarkable. When I joined the Ministry the predominant variant in service was the Mark V with 1,470 hp, full-throttle height increased to 19,000 ft, weight increased to 6,800 lb, and maximum speed raised to 370 mph. With the two-speed two-stage supercharger introduced into the Merlin 60 series, maximum power was 1,710 hp with a full-throttle height of 29,000 ft, weight increased to some 7,500 lb, top speed to over 400 mph, and with ceiling spectacularly increased. When the Griffon replaced the Merlin in the Marks XII, XIV and 21 with 2,035 hp, weight had increased to some 9,000 lb, and top speed to 460 mph at high altitude. By now even this was introducing compressibility problems, which redesign into the Spiteful with thinner wings was aimed to avoid, but the type was not entirely successful and, as with the Fury, it was dropped in favour of the new jet-propelled types, although as mentioned earlier the wing was adapted for use on the E.10/44.

Apart from having problems of drag estimation we had reached a level of performance where calculation of exhaust ejector effect and propeller efficiency was both difficult and critical and involved a lot of effort.

In reviewing the advances in performance which were achieved with the piston-engined types we must not forget the evolution of the Mosquito, which progressed from 18,000 lb and 375 mph with 1,460 hp Merlin XX-series engines to over 25,000 lb and 420 mph with the 2,050 hp Merlin 100 Series engines, and

to the following Hornet which, with a weight of 18,000 lb, had a top speed of 470 mph, and about 395 mph at sea level.

The later developments overlapped with the early jet-propelled types coming into service, although the first such type, the Meteor I, could only reach 410 mph. It was not long, however, before the Vampire took us up to 530 mph, and with the Derwent V revitalizing the Meteor to 585 mph the 440 mph of the Tempests and the 490 mph of the abandoned Spiteful were left well behind.

Rather as an aside, the period during which I was engaged in this work was during the V.1 and V.2 attacks. I seemed to have a fatal attraction for the former. My last night in Southampton coincided with such an attack on that area. When I went home for Christmas 1944 I encountered the air-launched attack at the mouth of the River Humber, when some of the 'doodlebugs' reached as far as Manchester. With the wretched things streaking over at very low altitude, and me in a house in open country immediately behind the coastal anti-aircraft guns, was about my most scaring experience of the war. I even left my bed for shelter, much to the consternation of my parents, who were accustomed, during the heavy air raids on the Humber Area in 1940-41, to my either staying in bed or going outside to watch.

Our office on the 5th floor of Thames House, Millbank, overlooked the river, with the premises of the London Fire Brigade (where an Imminent Warning flag was hoisted) directly opposite. We had a magnificent view to the south-east and foolishly used it to observe progress, making a last-minute dive for cover only when it seemed necessary.

This, I think, is fairly typical of the attitude of most of the civilian population to the horrible things. If one was inside when one passed over, the vibration from the pulsating jet was indescribable, but at least one knew that it was passing over. If outside, provided one had some shelter to dash for if the engine cut, it was fascinating to watch them. I remember one evening walking to my digs from Southall station and hoping to make the shelter of the house in time. I failed to do so, and suddenly saw a pair of them coming over together, each alternately taking the lead. There obviously was not too much precision in the engineering. Overall, with these attacks one often had a few seconds of near panic, but no more, so that on most of the population there were no long-term adverse effects on morale.

It was my opinion, and was certainly true of myself, that the opposite was the case with the V.2 rocket. I well remember the first to land, in the London district of Chiswick, and officially attributed to 'a gas-main explosion'. Due to one of our staff residing adjacent to the point of impact we knew better, but with a succession of subsequent unheralded bangs it soon became obvious to all that we had passed the credulity level of the unreliability of gas mains, and the truth was released. For many months unheralded bangs peppered the area day and night, with occasionally horrific damage or casualties. However, if you heard the bang you were safe, and there was no pre-bang pandemonium as could happen with the V.1. Nevertheless, after many months of this I began to feel jaded, and was glad occasionally to train up to Lincolnshire on a Saturday afternoon and back again on Sunday evening just to get a break. In this I was lucky; others had to sweat it out full-time, and the strain seemed to be telling.

Eventually it all stopped, to be followed in rapid succession by the end of the war in Europe and later in the Far East.

With hostilities over, the staffing level of the Ministry was bound to decrease substantially and the pace of events slow down considerably. As a young wartime temporary aged 22 I saw my immediate career prospects as poor. Priority was to be given to the over-30s. What was then left was largely for the bottom grades, and even that was to be subject to competition. I decided that my best course of action was to return to industry, and thanks to the good offices of Captain Liptrot I found myself in the summer of 1946 working in the Stress Office at Westland Aircraft in Yeovil.

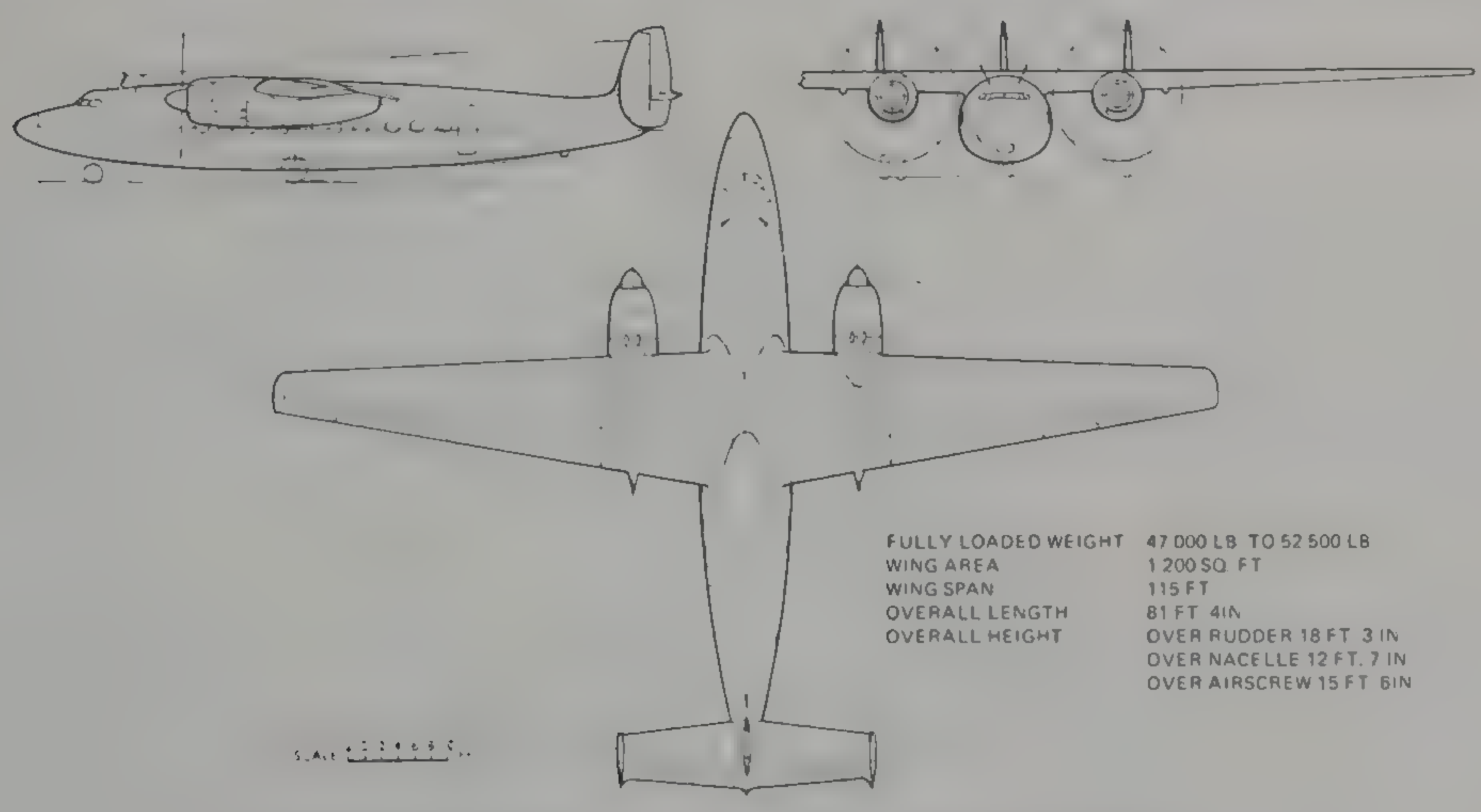
With the combination of the post-war lull and the nature of the work given to me I found life rather dull, although one job on which I worked was a proposal to redesign the front end of the Wyvern to take a tricycle undercarriage and an Avon jet engine. This used a box-beam portal frame connected to the main wing spars with the main engine thrust mountings attached to two uprights which had tubular bracing back to the main bulkhead. The stressing problems were quite horrendous.

The Vampire NF.10. *(A4592/5)*

Chapter 3
The Ambassador

My sojourn at Westland consisted of a few brief months, during the course of which I got married. When a vacancy on aerodynamics and performance was advertised by Airspeed at Christchurch I successfully applied. After a mere three weeks residence in the half-house which I had rented some two months previously, one Sunday in October 1946 saw Joyce and me, complete with trunks and bicycles, undertaking the train journey from Yeovil to Bournemouth, including the logistic nightmare of changing stations at Dorchester. We were bound for what hopefully was a temporary bed-sit on the northern outskirts of Bournemouth. Professionally it was a very happy move, but domestically it was less so, particularly with the birth of my first son approaching. Property prices in that area were highly inflated at that time, and buying was quite beyond my means. Council housing on a points basis was strongly weighted in favour of long-term local residents. The problem was eased by the initiative of a group of people at the factory, who persuaded Christchurch Council to build two-bedroomed flats in the large Nissen huts of the communal site of the disused Holmsley South airfield. There we spent the next two and a half years, well removed from other civilization, cooking by paraffin, with electric light but no electric power, and using our engineering skills to improve conditions by the adaptation of various discarded equipment found lying about the site.

In this environment a great team spirit developed which, of course, read across to working relationships at the factory. In any case that was not really

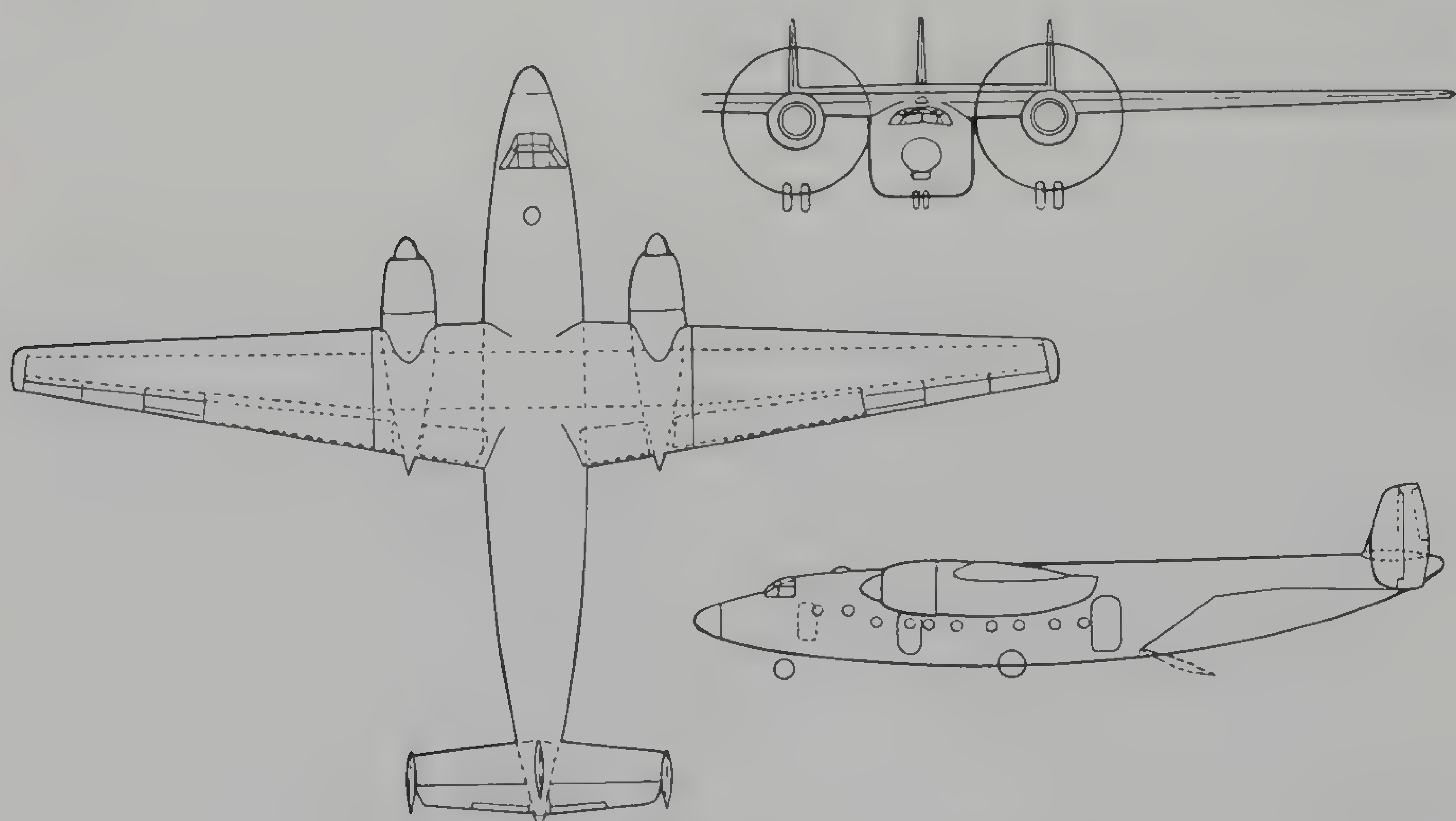


The Airspeed Ambassador — general arrangement.

necessary, as Airspeed was a happy place, notwithstanding the unapproachable Arthur Hagg being referred to as God, and his front office as God's Palace. Typically, Johnny Johnston, Alf Ellison, George Jewett, John Foss and 'Chappy' Chapleo headed up the design team in an excellent atmosphere.

My duties turned out to be exclusively on the AS.57 Ambassador airliner, and possible variants, encompassing performance, technical sales and project work. During this time we were joined by a person who had a profound effect on my thinking throughout my career. Roman Szukiewicz had qualified as an aeronautical engineer in Poland, flown with the Royal Air Force on operations, finally becoming a test pilot at the Airborne Forces Experimental Establishment then located nearby at Beaulieu. As we sat wrestling with a problem, in his fragmented English he would say 'Pilot, he say, Pilot, he think'. There can surely be no more apposite interjection into the thoughts of an aircraft designer.

When I arrived at Christchurch, construction of the two AS.57 prototypes was proceeding apace and the future of the military transport derivative, the AS.60 Ayrshire, for which a substantial order had been placed, was under review. The



The Airspeed AS.60 — general arrangement.

saga which took place around this latter type is told by Michael J. F. Bowyer in *Air Pictorial* of February 1984. My first task at Christchurch was to recalculate the performance of the Ayrshire. Unwittingly I drove a large nail into its coffin, as I gave considerably more pessimistic prediction than had up till then been quoted. The order was cancelled and, with no orders for the Ambassador then in sight, things did not look too promising. Certainly I had made an inauspicious beginning.

There then began a period of intensive work to improve the marketability of the Ambassador. This was a period when the new PICAO (provisional ICAO) requirements emerged with some more severe performance levels to be met, and route analysis and operating cost estimation became part of the daily routine. On operating costs, the American ATA method had been published and was regarded in many quarters as the standard, but we felt it to be too

American-operation oriented and developed our own. Subsequently the Society of British Aircraft Constructors tackled the problem, and I played an active part on the working sub-committee on this topic, both while I was at Airspeed and later after I had moved to Blackburn.

We were also unhappy with the PICAO climb requirements, based as they were on the American domestic requirements on aircraft stalling speed. We supported as best we could the United Kingdom efforts to produce new British Civil Airworthiness Requirements, based on the more logical drag/weight ratio.

Meanwhile, we courted and very nearly obtained a number of potential customers, but the Airspeed board of directors had evolved a policy of not selling the Ambassador abroad in advance of an established domestic operation. This condition appeared in the end to be met when, in December 1947, an order for 20 was placed by British European Airways. Attainment of this had followed a series of intensive design studies and a number of design changes, which certainly resulted in a much improved product. The sale, however, was not entirely related to the characteristics of the Ambassador but was also influenced by worries about the practical operation of the previously favoured Vickers V.630 Viscount, powered by four 1,000 hp Dart turboprops. There was at the time the proposal to produce a development of the Ambassador with four 1,580 hp Napier Naiad turboprops, and we stressed the wing for this. The advent of the 1,500 hp Dart and the 700 and 800 series Viscount gave a very different picture, but the two types operated successfully in parallel for several years. In the course of the final negotiations with British European Airways I did have the satisfaction of being rushed up to Peter Masefield's office with the final data, which resulted in the order being placed and which to some extent offset my disastrous contribution to the future of the Ayrshire.

I think that nobody who worked on the Ambassador could have failed to love it. It was beautiful to look at, beautiful to hear with the purring Centaurus sleeve-valve engines, and a delight to fly in. Certainly I have retained a deep affection for it to this day.

There is no doubt that the overall conception of the Ambassador was due to the genius of Arthur Hagg. Although responding to the requirements postulated by the Brabazon committee for the Brabazon 2, Hagg regarded both the size and the specified cruising speed as inadequate, and also continued with his fine eye for line and cleanliness already coupled with his name with the Comet racer and the pre-war Albatross.

He insisted on a high cruising speed, to obtain which with a twin-engined aircraft gave engine-out performance some three times that specified by the then current BCARs, and which fortunately still met the much more severe PICAO requirements even at the higher weights at which the Ambassador went into service. There were good technical and economic arguments in favour of the twin as opposed to a four-engined solution, but there were enough supporters of the opposite for it to be a matter of continued debate.

Cleanliness was sought in a number of ways. The streamlined fuselage, based on airship theory and also to be seen on the Constellation was one, although subsequent experience tends to discount the benefits originally claimed for it. A powerplant entirely conceived by the airframe manufacturer was an innovation. The smooth nacelles of the Ambassador had no excrescences. Externally opening cowling gills were eliminated and replaced with inwardly opening louvres,

cyclinder cooling baffles and bay-mounted accessories designed to minimize pressure drop across them, and a spinner fan added to boost the cooling flow to the amount required.

A NACA laminar-flow wing section was chosen, with transition to be, hopefully, at 50 per cent chord. To retain the necessary smoothness, the outer wings were designed as box beams with reinforced skins taking much of the bending loads. With engine nacelles, undercarriage bays and slipstream affecting the inner wing, there was no chance of obtaining laminar flow in this area, so this was built on more conventional lines which, with the large cutouts necessary, had heavy spar and rib construction.

It had become apparent that in practice, due to dirt and other factors, extensive laminar flow was a pipe-dream, and in any case the Ambassador had a significant skin joint at 20 per cent chord. This was one of my reasons for having reduced the performance of the Ayrshire, which had also to be applied to the Ambassador.

In spite of all not being as well as Hagg had desired, the Ambassador did have a remarkably low drag for its time. Using a drag index figure of profile drag at 100 ft/sec divided by total wetted area, the Ambassador had an index figure of 0.053. Contemporary American airliners averaged about 0.054, whilst the contemporary British airliners — which were mostly conversions or adaptations of wartime types — had an index of 0.064. The pre-war Albatross, which was regarded as the epitome of cleanliness for its day, had an index of 0.056.

With the high level of engine power incorporated, takeoff performance was much improved over earlier types, and something had to be done to reduce landing distances to match the takeoff capability. The tricycle undercarriage and the newly introduced disc brakes opened up possibilities provided that wheel locking with the braking power now provided could be avoided. Foot-pedal pumping to avoid this tended to reduce the braking power to one-third of that available, but if an automatic anti-wheel-locking device could be fitted the desired level of performance could be attained. With this idea in our minds we were delighted to welcome from Dunlop the Maxaret system.

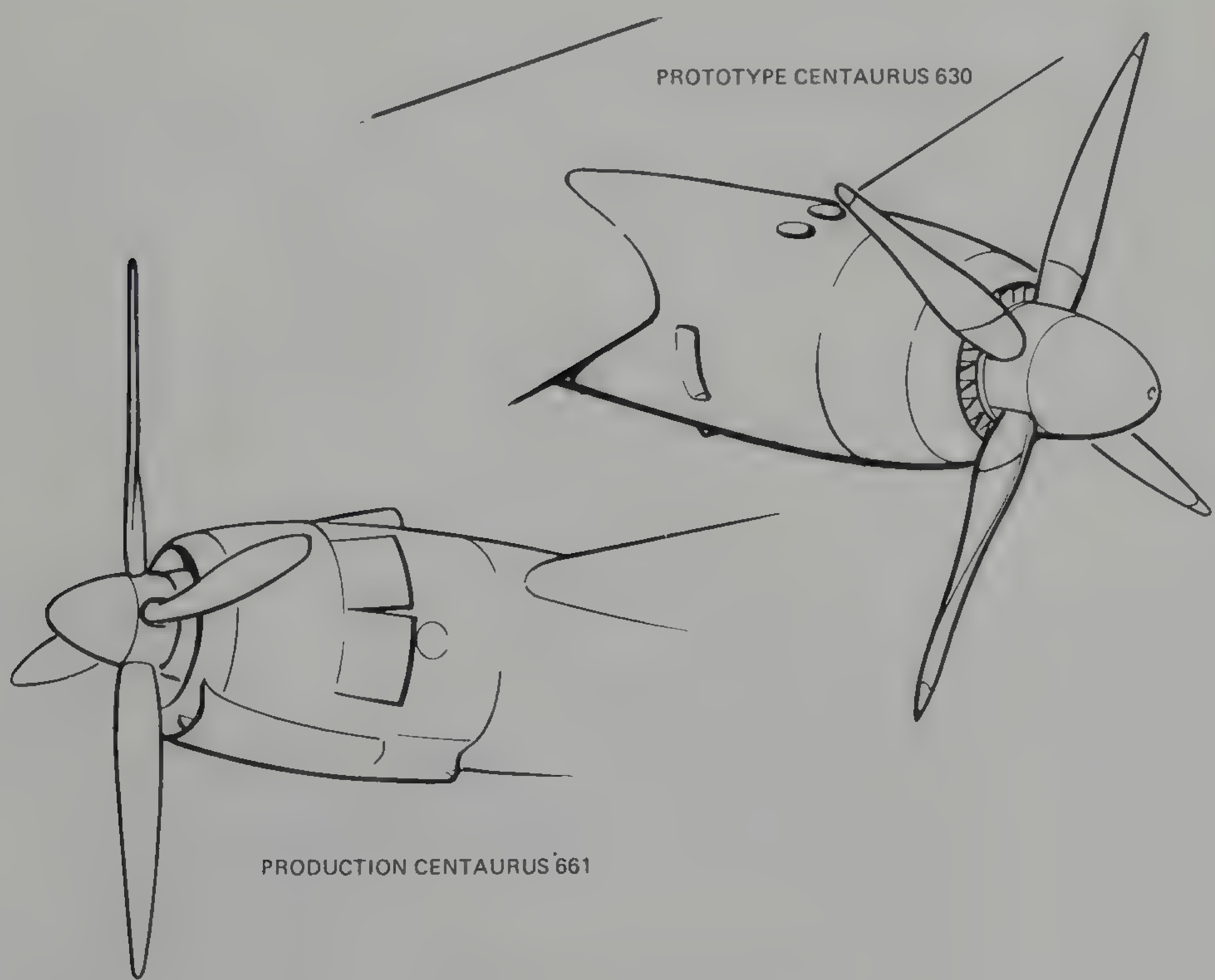
Another limiting factor which emerged upon us was the PICAO engine-cut climb after takeoff requirement, which specified that the dead propeller should be windmilling, whereas with the BCARs against which the aircraft had been designed the propeller was to be feathered. The drag of a windmilling propeller in fine pitch, into which it would naturally go, is greater than the profile drag of the clean aircraft, four times that of the propeller windmilling at the coarse-pitch stop (if it can be induced to take up that position) and 14 times that of a feathered propeller. We therefore advocated an automatic mechanism to throw the propeller at least into coarse pitch, or if certain problems could be overcome, to feather it in the event of loss of engine power. Fortuitously, Bristol had incorporated a torquemeter into the Centaurus engine for reasons of their own. This was coupled to the propeller mechanism to give the desired result, and hence a major enhancement of safety in service at the weights eventually operated, which was a maximum of 52,500 lb compared with the 47,000 lb which had earlier been envisaged.

To further improve airfield and climb-out performance we had been strongly advocating the use of slotted flaps in place of the simple split flaps as fitted. This would have been of considerable benefit, but all of our proposals were turned

down on the pretext of retaining engineering simplicity, at the time that the Viscount was adopting a flap system even more adventurous than our proposals. Obviously Fowler flaps would have been even better.

In the course of my initial assessment of the performance of the Ambassador I expressed doubts regarding the cooling adequacy of the spinner fan and inward-opening louvres, in spite of the steps taken to clean up the internal aerodynamics. I must have repeated this prediction more often than was good for me, for when my prediction was borne out I was given the task of proposing a new installation. As every politician knows, it is much easier to criticize what exists than to replace it with something significantly better. Up to this time British radial powerplants had been developed by the engine manufacturer on a more-or-less rule of thumb basis. The inner cleanliness of the Ambassador powerplant was new, and available data showed that the total pressure drop could be anything from 50 to 100 per cent of the pressure drop across the cylinders, the value of which was well established. I had a very difficult time trying to sort things out. The availability of a Pratt & Whitney handbook helped a certain amount, and at the critical moment a work of reference by Hartshorn and Nicholson of the RAE appeared, and I then had sufficient tools. Despite this it was still a heavily assumption-based exercise.

One of the problems was in finding sufficient exit area of the required efficiency. The twin exhaust stacks occupied much of the upper circumference, and the oil cooler, now with its own external intake, much of the lower part. There was therefore only room at the sides. In the end I calculated the exit area with externally opening gills over the maximum of the circumference possible.



Ambassador Power Plants.

Of necessity, these gills had to be of very large chord. I had left Airspeed for Blackburn before the production installation flew. From the grapevine I heard that, while the cooling appeared to be quite adequate, the drag was excessively high. It seems that, when the gills opened the scheduled amount, due to a lack of stiffness, the suction on the gills caused them to suck open further, a defect which was relatively easily rectified.

Another technical trauma which arose on the Ambassador was when the strength-test wing failed on the rig at RAE at some 75 per cent of design load. This was bad enough but, when what were thought to be corrective measures had been applied, the specimen failed again at an only marginally higher figure. After a great deal of tribulation, and not a little help from outside the Christchurch organization, the cause was identified and can be regarded as something of a classic.

As stated earlier, the large span and hence flexible outer wings had been built as a box beam with the heavily reinforced skins taking much of the bending with the spars acting mainly as shear webs. Connection of the outer wings to the centre section was by bolts spaced round the torsion cell with shear connection from the spars by mating racks. The centre section with its engine and undercarriage connections and cutouts with heavy ribs and spars was exceedingly stiff, much more so than the outer wing in the region of their attachment to each other. The result was that, as load was applied, the centre section did not flex, causing the inner panels of the outer wing to distort to the point where the panels failed under classical buckling criteria — a classic case of how aircraft stressing depends on assumptions!

Another structural problem which caused much thought and controversy during the contruction of the second prototype, G-AKRD, was in relation to the skinning of the pressurized fuselage. The first prototype, G-AGUA, had been built without cabin pressurization. Following the policy used throughout the Ambassador that cleanliness is next to godliness, countersunk riveting had been used for all of the fuselage skinning. With G-AKRD it was a certainty that countersunk rivets would be inadequate to cope with the pressurization loads involved.

At this time, experience in the United Kingdom of commercial operation with pressurized cabins was near to zero. There was a great temptation to try spot-welding, but in the end it was decided that attainment of consistency of strength could not be guaranteed. Dome rivets were unthinkable, so the mushroom-headed rivet had to be tolerated. In all probability these incurred no measurable performance penalty.

When our joy at the receipt of the BEA order had abated to realism, many of us felt disappointment when it was stated that in order to have an acceptable amortization of the existing Viking fleet, the Ambassador would not be required in service until 1951. We felt that this gave a much slower programme than could be achieved, during which much of the market could be syphoned off, especially as Vickers had not accepted defeat and had gone on with the much more powerful Dart, to have on offer the 700 series Viscount.

Whether our thoughts in 1947 of an unduly extended programme being forced upon us were soundly based or not, in the event with the usual unexpected mishaps in a development programme, it was 1952, a year later than scheduled, when the Ambassador at last entered service. The story of this and the sub-

G-AGUA: the first Ambassador prototype. Note the original nacelles. *(A4591/7)*

G-ALZN Elizabethan, a production Ambassador in service with BEA. *(A4591 10)*

sequent service of the Ambassador is well told in *Airspeed Aircraft since 1931* by H. A. Taylor.

Having got into service use, as BEA's 'Elizabethan' class, the 20 Ambassadors gave a good account of themselves. As a result, some of the further hoped-for orders looked like materializing, but the parent company decided that, with an overall production workload arising from the Korean war and also the introduction of the Comet, better use could be made of the factory at Christchurch rather than continuing with the so-far unprofitable Ambassador.

Firm plans had been made for a turboprop development of the Ambassador and pick up points for four such engines had in fact been built into the second prototype, G-AKRD. The originally intended Naiad had failed to materialize, but the development of the Dart which had taken place had made it quite suitable for application to the Ambassador and firm plans for such a version, this time with our proposed slotted flaps, in the form of the AS.59 were made when the decision to terminate the whole project became known. How this would have shared the market with the Viscount must remain a matter for speculation, for each type had its admirers.

Before this sad state of affairs arose I had left Airspeed, which as a mere de Havilland factory was losing its identity. Although I was most happy at work, the housing situation showed no signs of improving. I travelled up to Grimsby for the wedding of a friend in the shipping business. He was being transferred to Hull, and had just bought a house there at a price less than half that in vogue around Bournemouth. The next week a post in the Project Office with Blackburn Aircraft at Brough was advertised. I applied, was taken on and there began another happy association where I finally rose to become Assistant Chief Designer in 1962, Chief Designer in 1966 and Executive Director and Chief Engineer in 1968, remaining there until 1978.

Chapter 4
Brough Future Projects, 1949-1978

It was in February 1949, immediately after the merger of Blackburn and General Aircraft, that I took up my post in the Brough Project Office. At that time there were still separate offices and factories at Brough and Feltham, but soon all activities were to be based at Brough.

At this time the factory had a modification line for the Firebrand, was building Percival Prentice and later Boulton Paul Balliol trainers, and utilizing the remaining shop floor capacity to manufacture Meteor and Vampire drop tanks and even bread tins. It was also preparing to receive for final assembly major components of the huge General Aircraft 60 Universal Freighter. The technical staff was largely occupied with the flight trials and development of the GR.17/45 anti-submarine aircraft, the YA.5, which was in competition with a similar project from Fairey.

The then Chief Designer, George 'Jim' Petty, had the reputation of being a very fine detail designer but no aerodynamicist. To save complication on the YA.5 he insisted on a single rather than a double wing fold, dropping the height when the wing was folded by putting pronounced anhedral on the inner wing. The first two prototypes were engined with the Rolls-Royce Griffon, but the third prototype and the production aircraft were planned to be YB.1s with the 3,130 hp Napier Double Naiad. Like the Naiad for the Ambassador, this failed to materialize, and recourse had to be made to the lower-powered 2,410 hp Armstrong Siddeley Double Mamba, as had been planned for the competing Fairey machine. As a result of this reduction in power the wing span was found to be inadequate, and I well remember Dennis Warburton working day and night to produce drawings for the emergency trial fit to extend the span of the third prototype, involving of course a double wing fold.

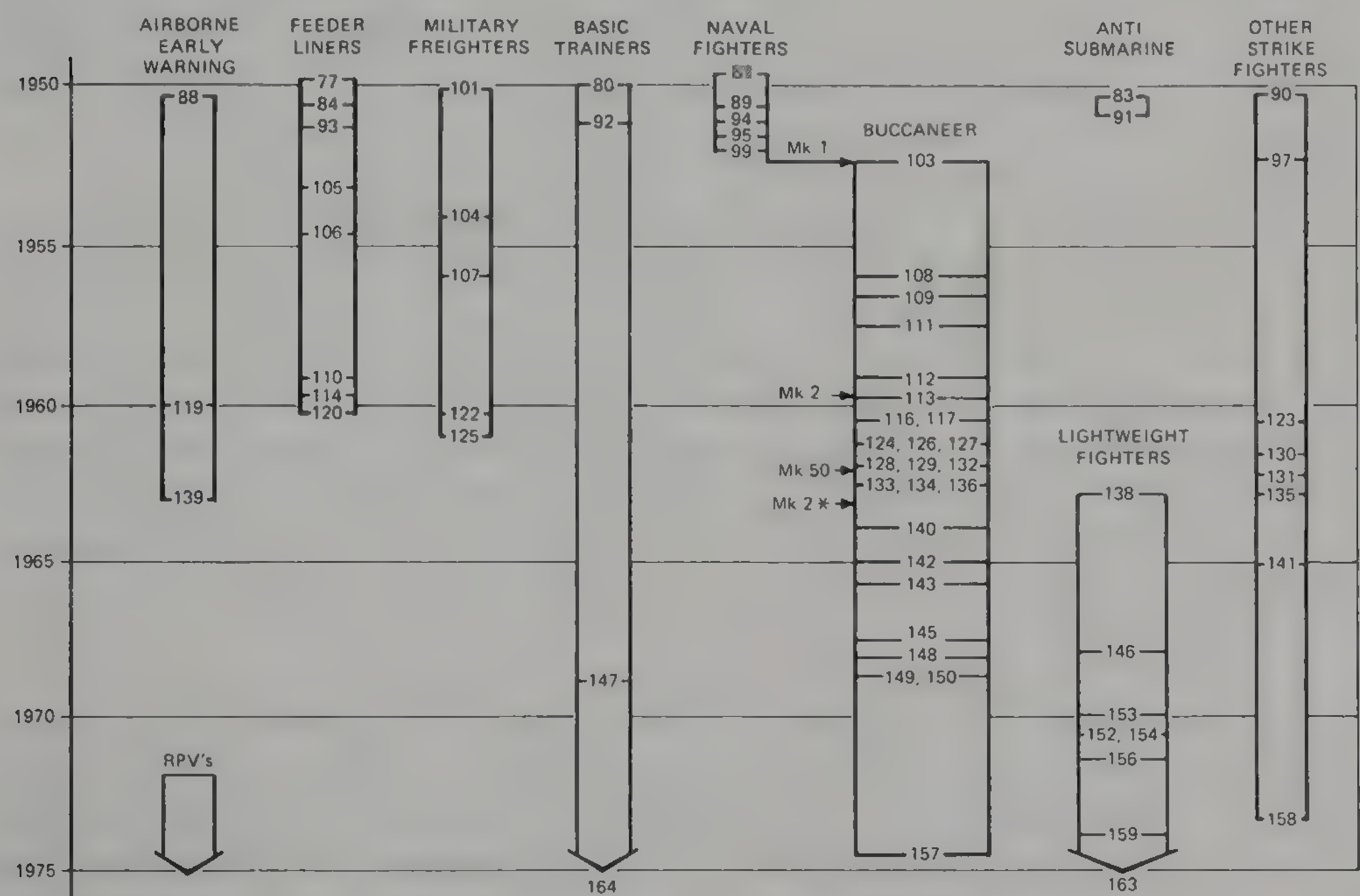
Meanwhile, flight trials had shown poor takeoff performance with flaps down. I did an analysis of flight results, and concluded that flaps-up performance was in agreement with prediction, but that flaps-down results suggested that a premature stall was occurring, presumably due to the proximity to the ground causing a choking effect arising from the inner wing anhedral. The same investigation suggested to me that the wing sections chosen were very conducive to a tip stall. Extending the span along the wing generator line, as was in fact done, could only exarcerbate this, and this is exactly what happened. Flight tests at Boscombe Down showed this up in alarming fashion — never to be forgotten by test pilot Doug Parker. As a result the order went to Fairey, and Brough with its strong Naval tradition was left with a large void to fill.

GR.17/45 anti-submarine prototypes. Below: the Double Mamba version. Above: the Griffon engined version. *(BAL)*

GAL 60 Universal prototype WF 320. *(BAL)*

Fortunately, the ex General Aircraft Universal Freighter was taking shape at Brough, two Hercules-engined prototypes having been ordered. Work soon commenced on the second prototype, and fortunately it was agreed this should be fitted with Centaurus engines, and have the rear fuselage completely redesigned to replace the rear doors with clamshell type, and with a rear boom capable of accommodating personnel. Alf Foster was drafted into the Project Office to prepare the drawings for this configuration, which was to become familiar as the Beverley.

However, with the hoped-for order for the GR.17/45 gone, and no production order in sight for the Freighter, things looked grim. They were not helped by a major organizational crisis arising between the Chairman and founder of the Blackburn Company and the two joint Managing Directors who had been appointed following the Blackburn and General Aircraft merger. Eventually the crisis was resolved, the dynamic Eric Turner became Managing Director and N. E. Rowe, in whose department I had worked in my time at the Ministry of Aircraft Production became Technical Director. The successful Brough organization of the next 20 years began to take shape, with Barry Laight joining in 1952 from Bristol to be Chief Designer. The first success was a production order for the Beverley.



Brough Projects, 1949-1977.

It was in this situation that we worked in the Future Project Office, desperate for a new project to fill the gap, but also wondering whether in a very short time we would be out of a job. The aircraft industry was that kind of industry.

Over the period 1949-1978 I was either a member of that same Project Office in one capacity or another, or in a higher appointment responsible for it. The variety and number of projects which passed through the office is by present standards surprising, and completely unlike the situation today.

Unfortunately, many drawings and much of the data have disappeared, but

the chart shows most of the activity by date and broad classification. With as much data as I have been able to retrieve from surviving archives, personal files and memory, it seems worthwhile to give as full an account of the projects as can be managed.

Anti-Submarine Aircraft, B.54, 83 and 91

Whilst work on the GR.17/45 was proceeding it was felt by the Royal Navy that it was too heavy and too fast to operate from some of the smaller carriers in rough seas. Vertical velocity on landing and the associated reaction were dominant factors. Nothing could be done about the effect on this from ship movement so the idea was to reduce aircraft weight as much as possible, primarily to reduce the approach speed from the 90 knots of the GR.17/45 to about 60 knots. We produced the Merlin-engined B.83 design (illustrated) followed in 1951 by the Mamba-engined B.91 for which unfortunately no data remain. From memory, it was very similar to the Short Seamew, which did reach the flight trials stage.

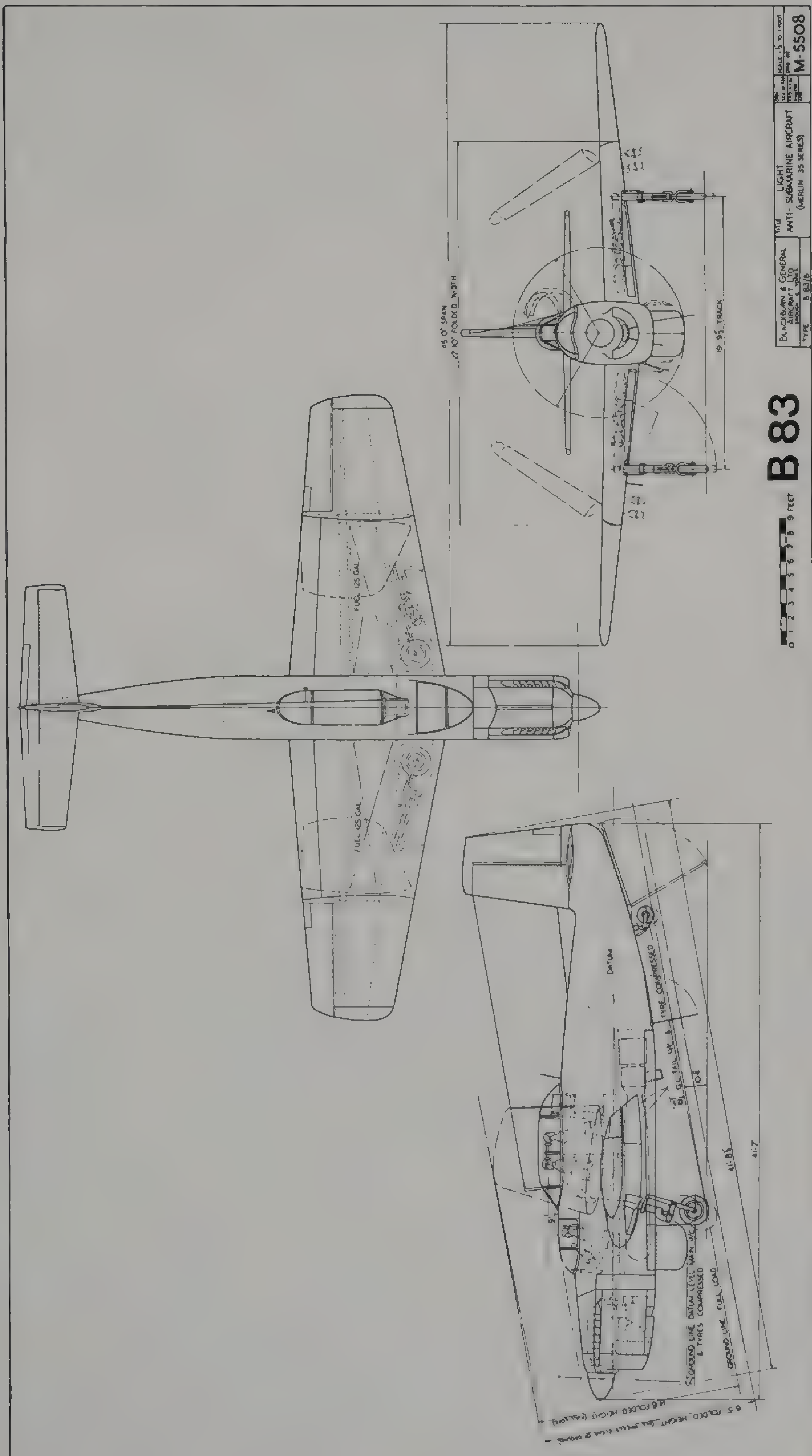
Having produced a design which met the requirements, it had of necessity to have a relatively low wing loading and very powerful flaps to develop the necessary high lift coefficient. On mature consideration we felt that the low wing loading would have undesirable effects in the turbulent conditions which could accompany a rough sea state, and the flap system needed to produce the required high lift would make the attainment of adequate lateral control very difficult if not impossible. We decided to opt out of the competition.

Some four years later we were at Boscombe Down facing an assessment team over our proposals against the NA.39 requirement. In the bar for pre-lunch drinks I happened to mention this thought to Lt-Cdr J. D. Glendinning, then of C Squadron. He called his colleagues over and asked me to repeat my statement. It appeared that the flight trials of the Seamew had just been completed, and resulted in the assessors reaching the same conclusion. From this our stock went up to some extent, countering the adverse memories of the GR.17/45, and I feel that this helped us on our way in getting a favourable decision in respect of the NA.39.

Airborne Early Warning Aircraft, B.88, P.119 and P.139

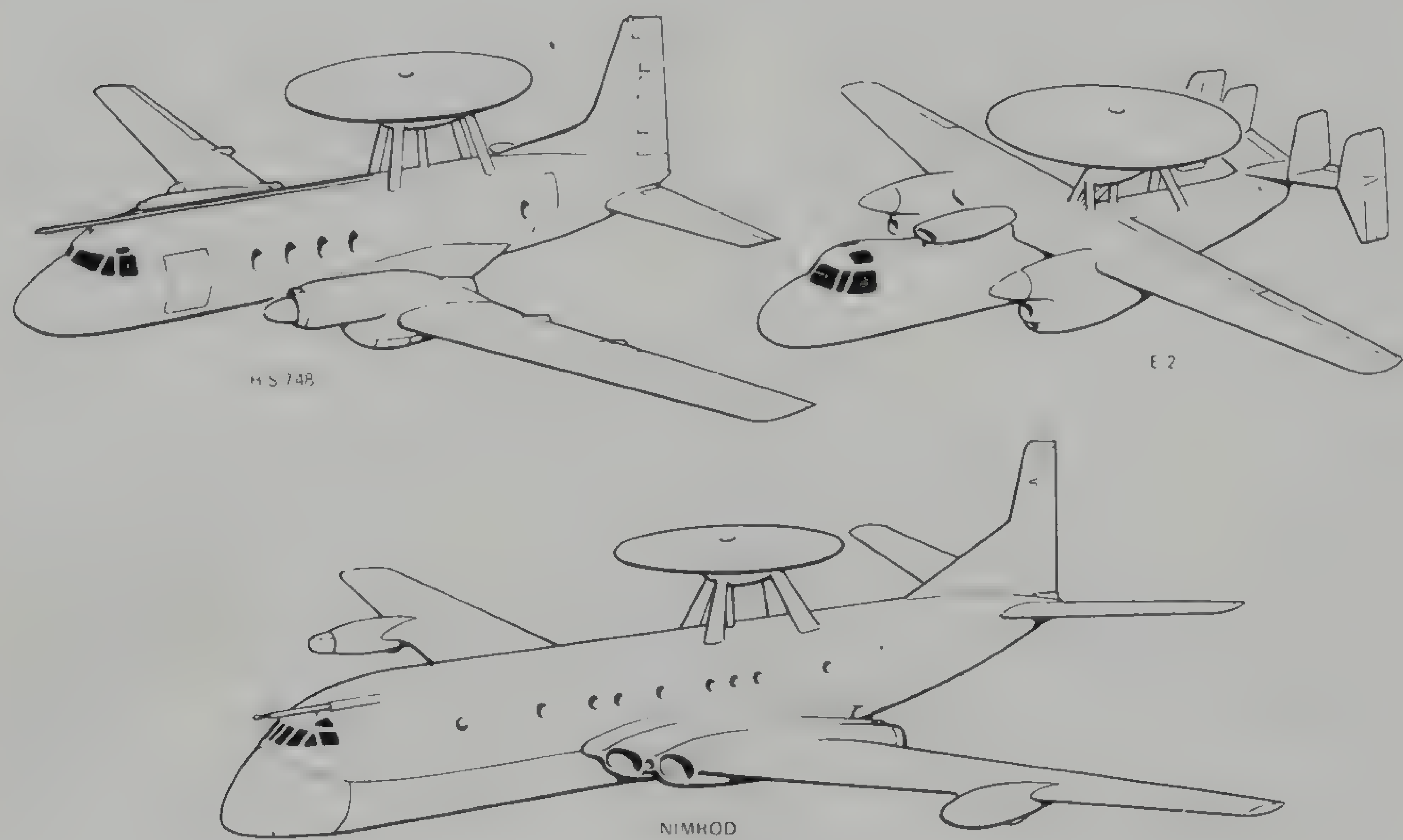
Over the years a series of studies were made for AEW (Airborne Early Warning) aircraft, in the main for Naval application. The first, the B.88 in 1950, was to mount the American Cadillac (APS-20) radar under the fuselage of the Blackburn GR.17/45. The same treatment was applied to the Fairey contender (subsequently the Gannet) which served this role faithfully for many years before surrendering its equipment to the land-based Shackleton.

Trying to look further ahead for protection of the Fleet, in 1961, with thoughts on commonality and the avoidance of developing a completely new type, we considered an adaptation of the Buccaneer with sideways-looking radar installed in place of the bomb bay, the aircraft to operate an orbiting profile to obtain all-round coverage. The resultant P.119 did not have the endurance considered desirable for such a role, and the radar solution was unconventional, so the proposal was dropped.



The B.83 — general arrangement.

In 1962 we received the first official requirement for a new AEW aircraft in the form of NAST (Naval Air Staff Target) 6166. This was a joint Royal Navy and Royal Air Force Staff requirement, with the rumour that the French Navy might also be interested. The Royal Navy, of course, required carrier compatibility. The Royal Air Force desired to have a short-field capability, so there was reasonable common ground between the two services, although the weight and dimensional limitations for deck operation were in fact prime drivers. The radar requirements were very stringent, and difficult to be accommodated in any airframe meeting the Royal Navy limitations.



Airborne Early Warning AMTI Radar.

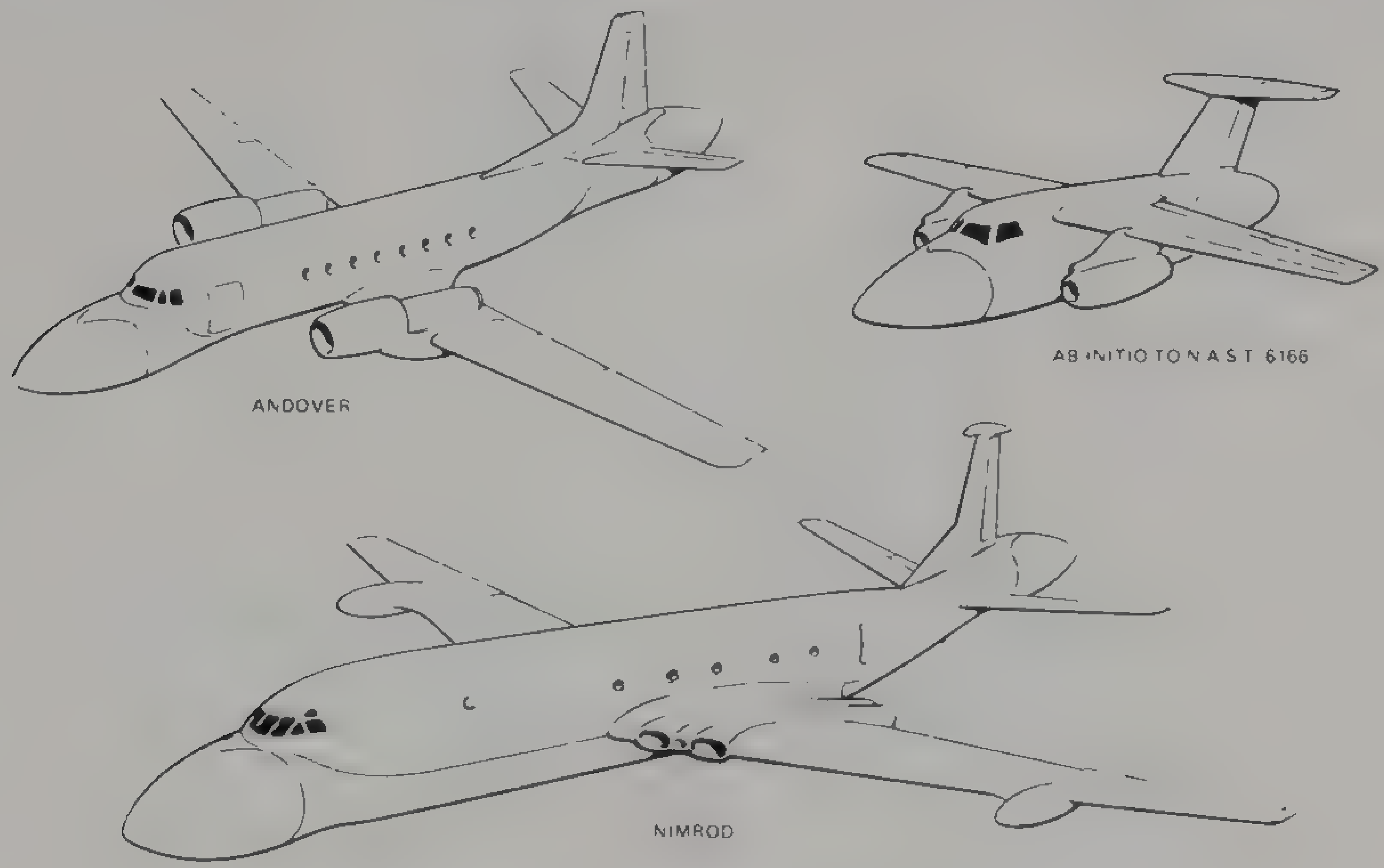
Mushroom and rotordome solutions were considered (see illustrations) on both new and adaptations of existing airframes, but none appeared to be feasible. We then came up with the idea of nose and tail mounted scanners to give all-round cover, leaving until later answers to the argument between one central transmitter with long waveguides or two switchable transmitters. There was on top of this a formidable data-processing problem to be overcome.

The outcome was the P.139, a short and stubby high-wing design with two turbofan engines, the type of radar chosen being considered to be incompatible with the interference from rotating propellers. The configuration was also considered to be compatible with a COD (Carrier on-board delivery) variant for which a need was known to exist. The Gannet did fulfil this role but its capacity was very limited. The Grumman C-2A Greyhound, a modified Hawkeye, fulfils this role with the US Navy.

The P.139 had a basic weight of around 28,000 lb, and a takeoff weight of 40,000 lb. Wing span was 61 ft, and wing area 500 sq ft. Engines were to be two Rolls-Royce Trents, a three-shaft engine of 9,980 lb thrust.

The project was aborted in 1965 on two counts. Rolls-Royce abandoned the Trent, and no suitable alternative could be found, and this was also the time when Denis Healey spelt out the death of Britain's seagoing airpower.

Protection of the Fleet many miles from shore was still a necessity, and we were asked to study an AEW version of the Nimrod with the system which we had proposed for the P.139 including the fore and aft scanners. The configur-



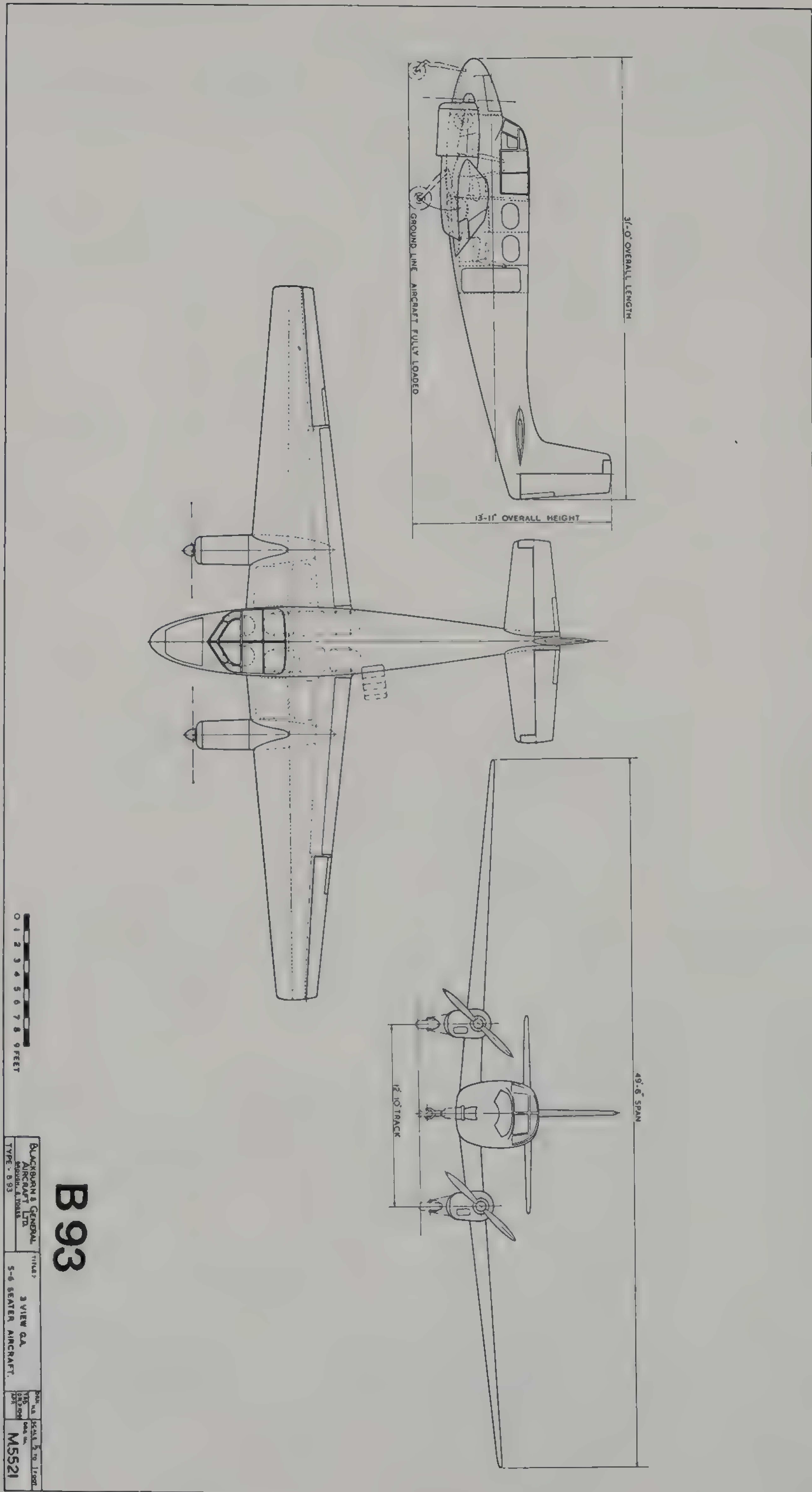
Airborne Early Warning FM ICW Radar.

ation was shown to be fully practicable and satisfied the stated requirements. Government circles considered it to be a very expensive solution, and with a number of Andovers scheduled to become surplus we were asked to investigate adaptation of these, accepting that flight refuelling would be necessary for the mission to be met. A proposal was drawn up and is illustrated, but again we found that an engine of the Trent characteristics was required but not available. After due consideration officialdom decided that the Nimrod was after all the preferred solution, but several years were to elapse before it was activated. By then Brough had a full workload, and it was decided that any subsequent work would be handled at the home of the Nimrod at Woodford. The story of the radar and data-processing problems with which it was beset, leading to its eventual costly abandonment in favour of the Boeing AWACS completes the Airborne Early Warning story to date.

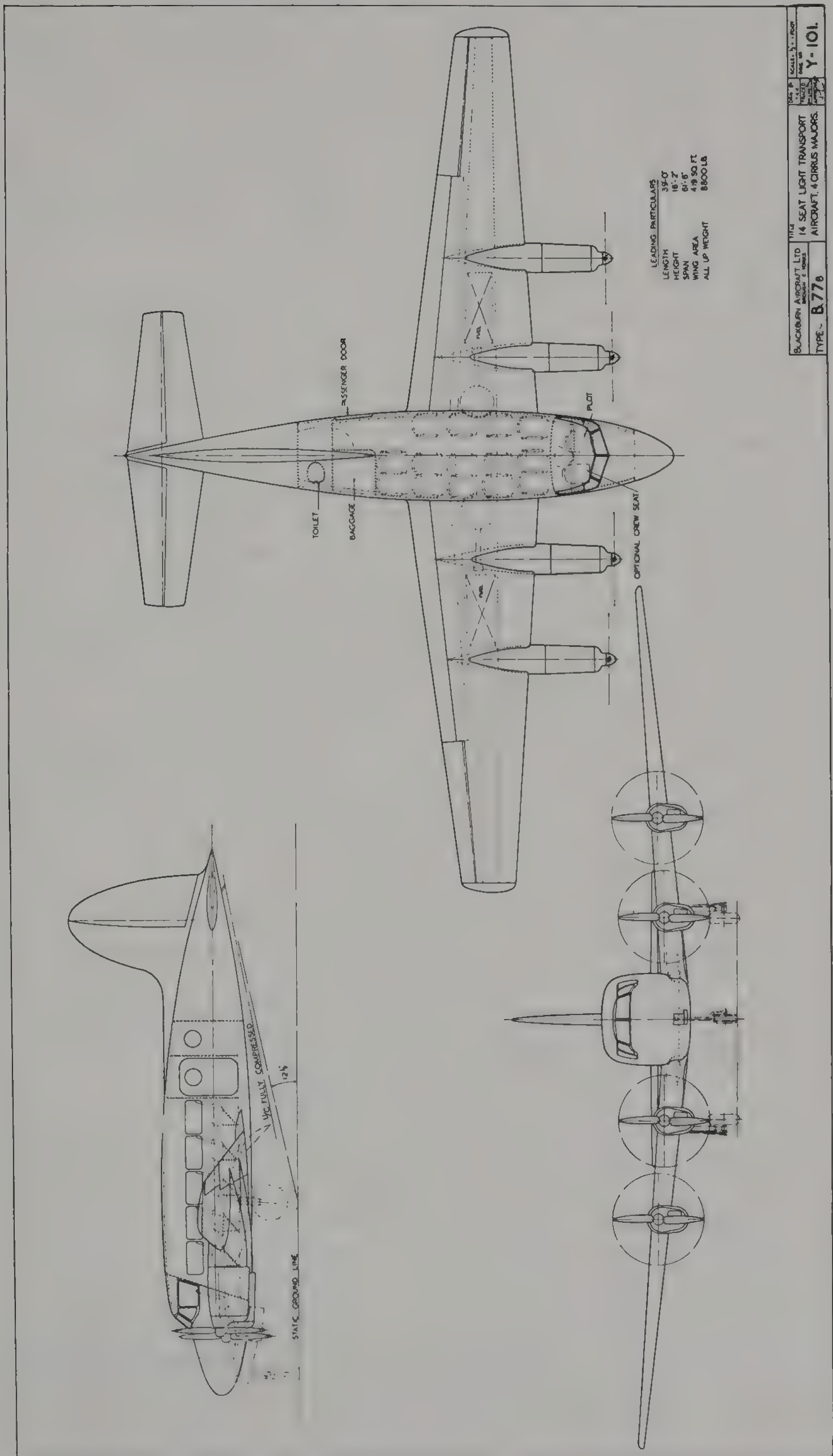
It may be of interest, however, that the AWACS requirement was not formulated until the late 1960s, with the development order placed in July 1970. It was the mid-1970s before the full USAF programme was approved. The United Kingdom was thus at one stage far ahead in the game, but, once more, failed to maintain the impetus and eventually gave up.

Civil Feeder Aircraft, B.75, 77, 84, 93, 105, 106, 110, 114, 120

From about 1949 onwards there was considerable interest at Brough in small civil aircraft. In the B.75 and later the B.93 of 1951 (illustrated) a 4/5-seater was investigated using the Brough-built 180 hp Cirrus Bombardier engine. Twin-engined, and weighing 5,000 lb, cruising at 200 mph, the B.93 had a range of 575 miles with five passengers or 1,100 miles with four. On two occasions the project nearly went ahead, but each time had to give way to higher-priority work and finance.



The B.93 — general arrangement.



The B.77B — general arrangement.

Concurrent with this much thought had been being put into a modern replacement for the de Havilland Dragon Rapide, which had been built in large quantities during the war, many of which were now being used for civil purposes. The Dove, with two 345 hp Gipsy Queen 70 engines and weighing 8,500 lb, had become available, but it was felt that a market existed for a larger-capacity aircraft with substantially better airfield performance. The B.77 of 1948 (illustrated) was the first Brough design in this category, powered by four 145 hp Gipsy Major X engines and with up to 14 seats in a basically three-abreast arrangement.

In 1949 Specification 26/49 was issued, mainly as a Rapide Replacement for British European Airways for use on their Scottish and Scilly Island routes. The aircraft was required to operate with a 600 yards (1,800 ft) takeoff to 50 ft with 12 passengers and baggage over a 75-mile stage. The B.84, again with four Gipsy Major X engines, was our submission. It had a wing span of 64 ft, wing area of 446 sq ft, and weighed 9,000 lb. With development of the 180 hp Bombardier proceeding apace, it was expected that this engine would succeed the Gipsy Major when the weight would increase to 9,500 lb. A stage length of 500 miles could then be flown with eight passengers.

In the course of this programme, de Havilland stretched the Dove, and with a new centre section carrying the existing outer wings and four 250 hp Gipsy Queen 30 engines, produced the Heron. Although not matching the specification, this did have an effect on the overall market. Miles Aircraft were also at that time with Government funding, developing the Marathon which had four 345 hp Gipsy Queen 70 engines, 20 seats and weighed 18,000 lb.

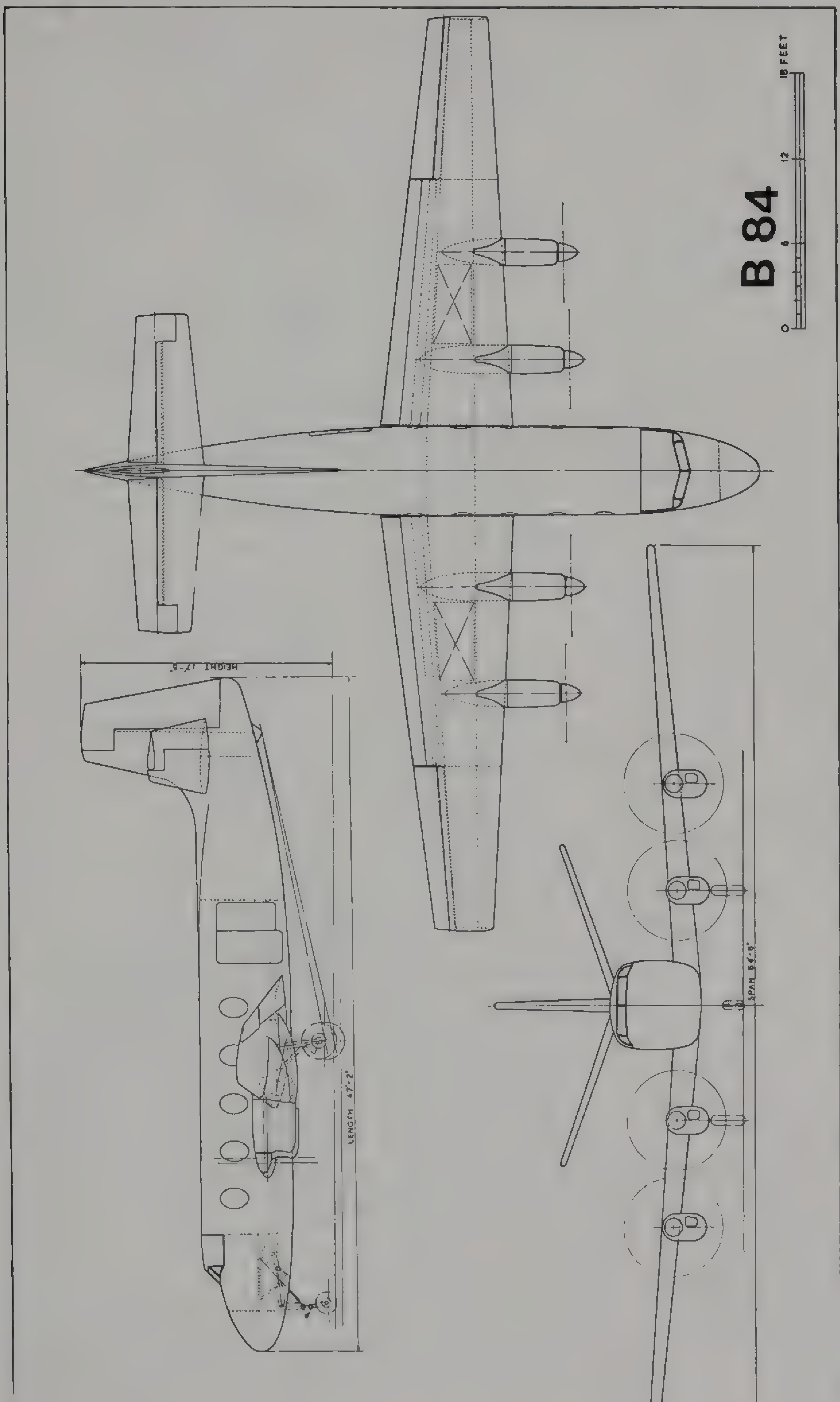
The assessment of the submission to Specification 26/49 left Blackburn as joint favourites, and we were living full of hope when it was announced that government funding for the project would not be forthcoming in addition to that already committed on the Marathon. British European Airways were to be instructed to make use of that type, although it did not match the critical requirements on a small number of the routes.

Disappointed at this, we did continue with the concept and in 1953, with the Bombardier engine now established, proposed an enlarged version, the B.105 (illustrated). This, with a wing area of 55 sq ft, 76 ft span, overall length 47.5 ft, and cabin length of 26.5 ft, had a basic weight of 7,800 lb and takeoff weight of 12,000 lb. Cruising at 170 mph at 5,000 ft, it carried a payload of 3,500 lb over a stage distance of 100 miles or 3,000 lb for 350 miles whilst requiring a grass runway of 700 yards (2,100 ft) to meet all safety rules fully.

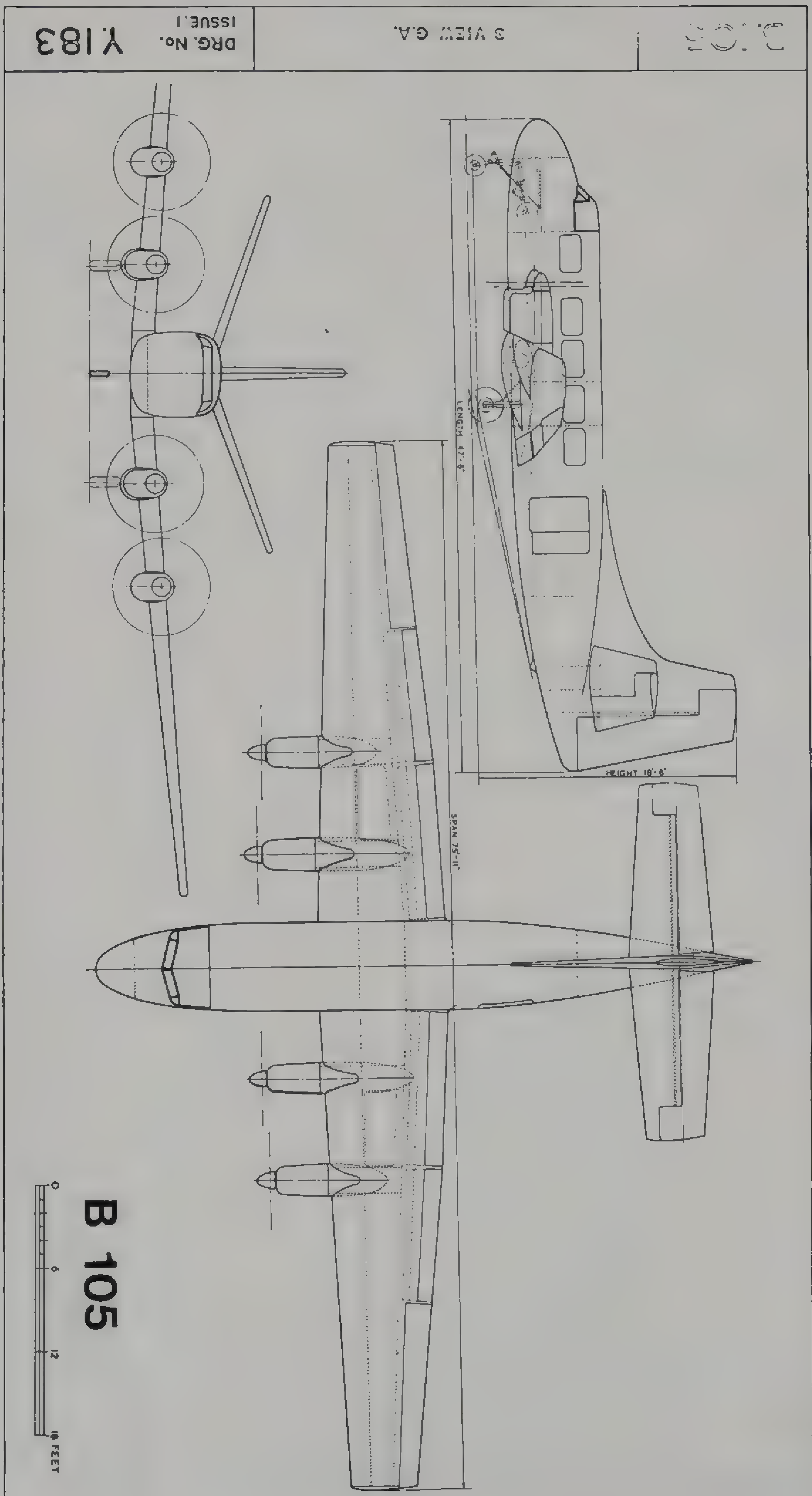
Following the agreement with Turbomeca for licensed production and development of their engines, a 26-passenger design using four 475 hp Marcadau turboprop engines was studied. Route studies for both United Kingdom and overseas application suggested that the design should carry capacity payload over a stage length of between 200 and 300 miles, and be capable of operating from 1,000 yard (3,000 ft) airfields.

The B.106 design (illustrated) had a wing area of 750 sq ft, span of 87 ft, overall length of 57.5 ft, pressurized cabin 6 ft high and 33 ft long, basic weight of 12,200 lb, and takeoff weight of 22,500 lb. With a cruising speed of 240 mph, a payload of 8,000 lb could be carried for a stage of 100 miles, or 7,000 lb for 300 miles, operating from an 875 yard (2,625 ft) runway.

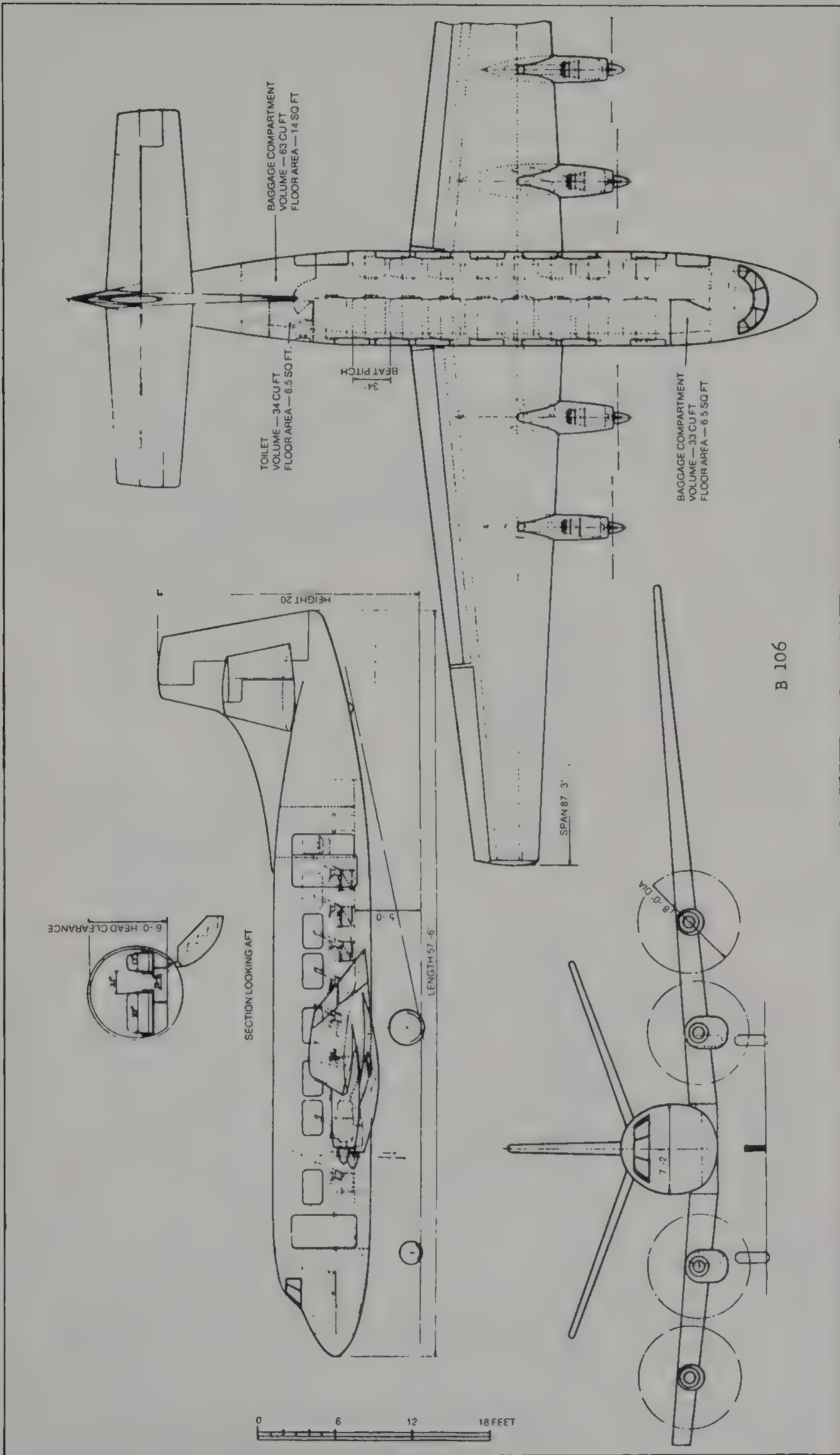
With hindsight, it was probably good fortune not to become involved with this



The B.84—general arrangement.



The B.105 — general arrangement.

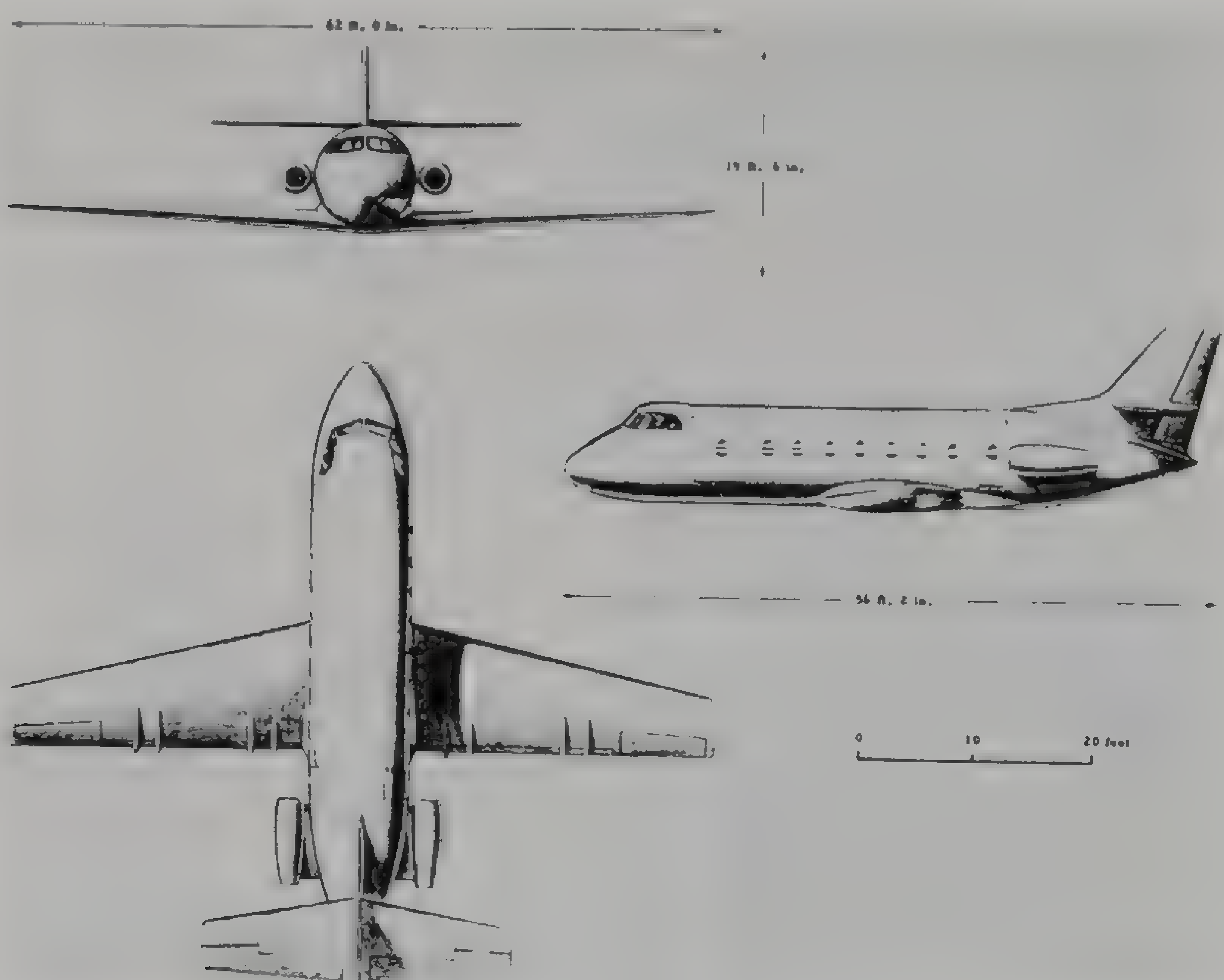


The B.106 — general arrangement.

class of aircraft. A study in 1951 showed that in developed countries it required a stretch of water to be crossed before air transport could economically compete with surface transport below stage lengths of at least 150-200 miles, and that a number of routes with scheduled services which fell into the right category where the traffic was of the level appropriate to the size of aircraft, and which had airfields from which the very short takeoff and landing distances were necessary, were relatively few. Those routes which were appropriate soon became the province of the helicopter, and others offered sufficient traffic to be more economically operated by cheaply acquired secondhand aircraft of larger capacity, albeit operating at low load factors. Many of the routes considered have, with the growth of traffic,which has occurred, been efficiently operated by the Fokker Friendship, Hawker Siddeley 748 and Dart Herald class of aircraft.

Following this phase, there was a long gap before another civil project was active at Brough. The B.110 28-seat airliner proposal was, with the rationalization which took place within the Hawker Siddeley Group, transferred to Hatfield where it was integrated into the D.H.136 programme. This, after a long period of gestation, grew into the much larger Hawker Siddeley 146.

The B.110 project was based on a literal replacement for the Dakota, to carry 28 passengers over stages of between 175 and 250 miles cruising at 340 mph, and



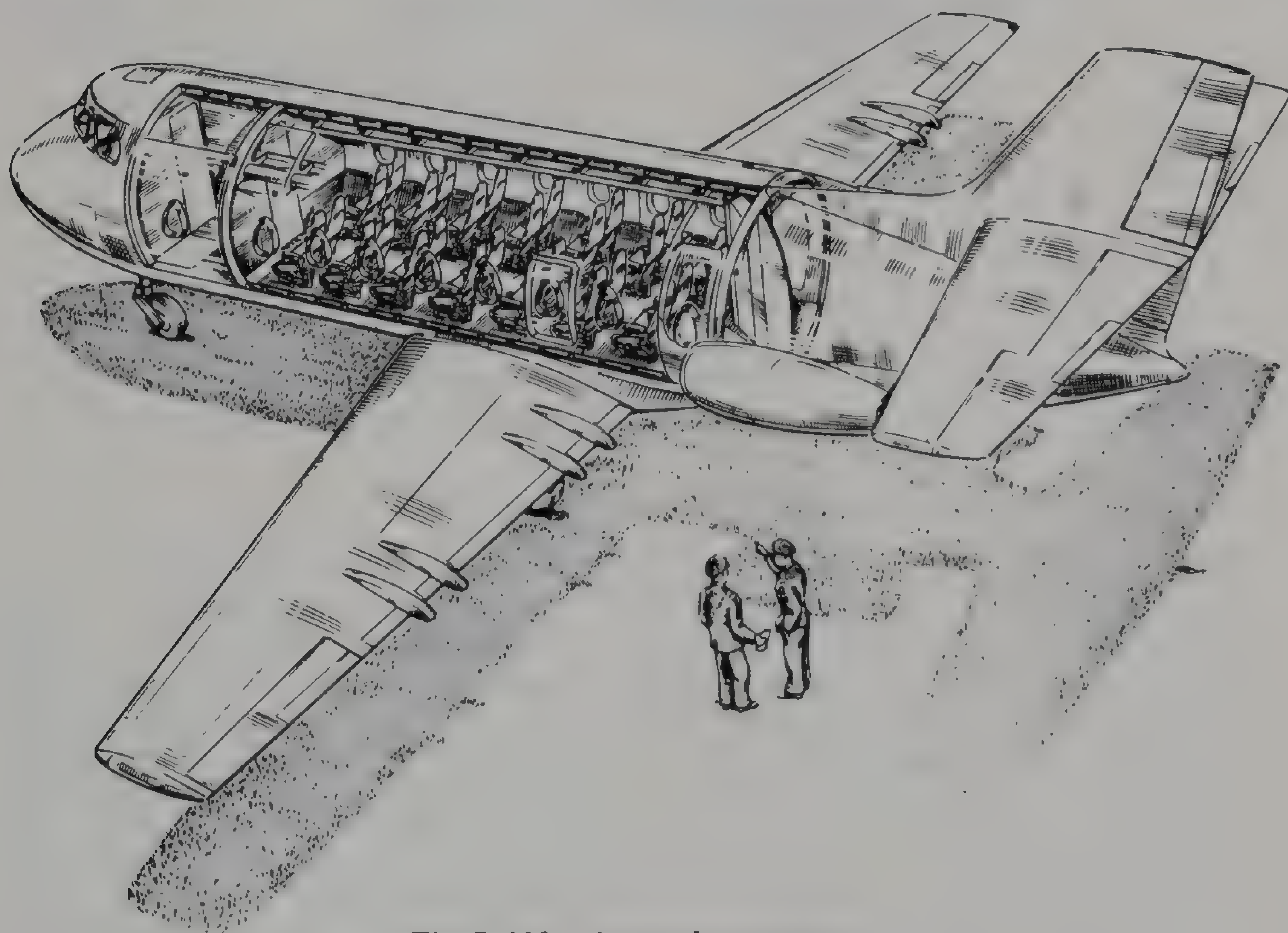
The B.110 — general arrangement.

able to operate from 3,300 ft grass airfields. Turboprop, jet and ducted fan engines were all considered. For the operating conditions envisaged, the ducted-fan solution was preferred, with two 3,200 lb at 45°C engines which were based on Rolls-Royce RB.150 data. The planned aircraft is illustrated, with dimensions of 62 ft span, 59 ft length and a wing area of 538 sq ft. Empty weight was 11,200 lb, and takeoff weight 19,600 lb.

Much detailed design work was done on the B.110, and for its time many advanced features were incorporated, but it did require the development of a

completely new engine. The concept assumed that enough of the many short hauls then operated by Dakotas and similar types would not require increased payload capacity, and that with an estimated selling price of £110,000 buyers would be found for between 200 and 500 units. Again, hindsight shows that to have embarked on such a programme would have been a disaster, both on account of the diminishing market and on the risk level of the degree of technical innovation which was proposed.

For some time, forward thinking at Brough had been investigating the potential of the cold jet flap allied to, for those days, a high-bypass-ratio

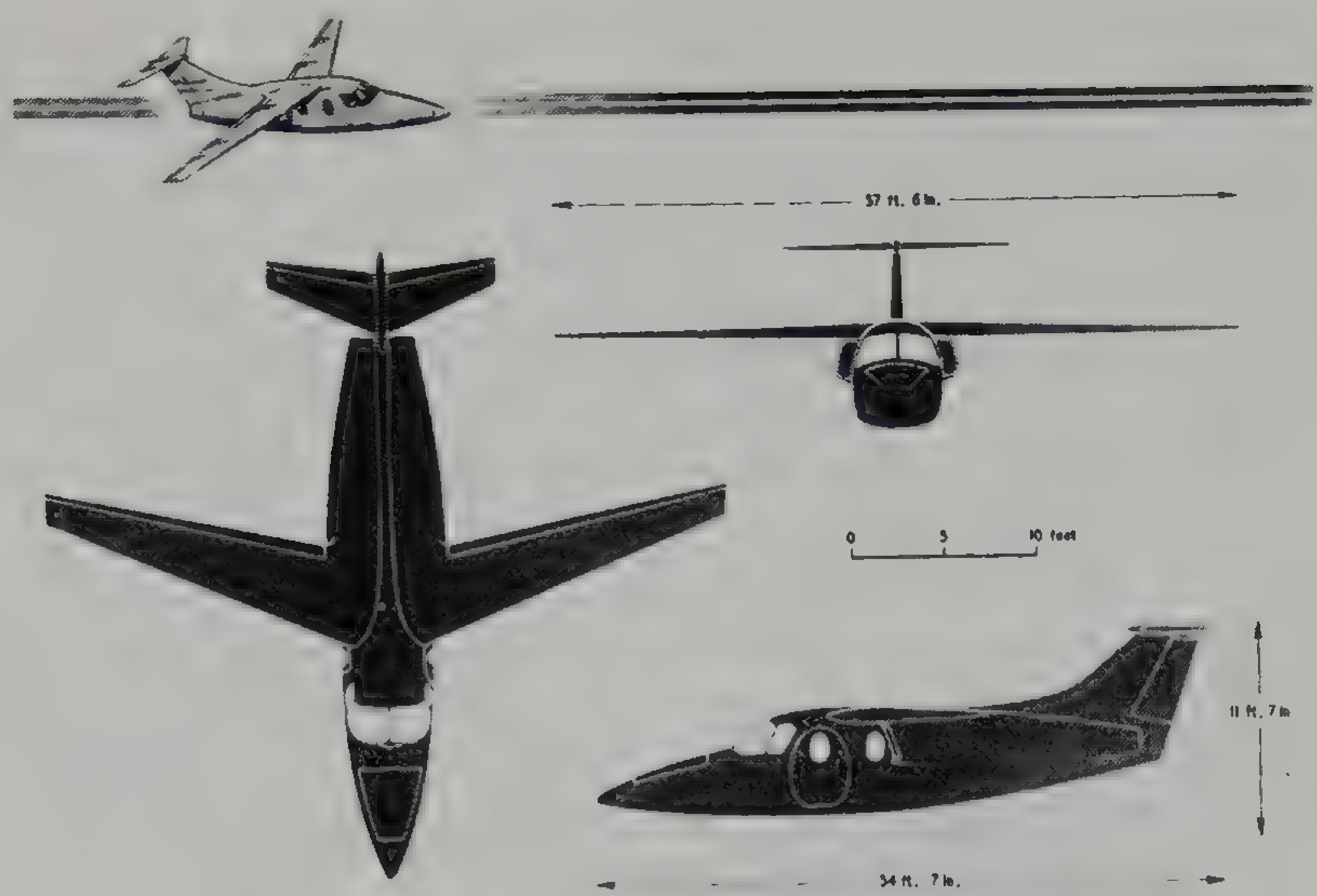


The B.110 — internal arrangement.

turbofan. In this concept a large proportion, or even all, of the bypass air is ducted along the wing trailing edge and discharged over a short-chord flap. In this arrangement, the momentum of the jet sheet can be applied to normal propulsion or, taking advantage of the Coanda effect, turned downwards over a deflected trailing-edge flap. In the latter case, apart from jet-deflection effects, very large lift coefficients can be generated. It was felt that the principle could usefully be applied to give high cruising speed and short field performance for a small VIP or executive transport.

With various projected engines reviewed, the proposed Bristol Siddeley BS 85/2 was selected, and the B.114 design put forward. This, as illustrated, was a high-wing design, able to take pilot and four passengers over a stage distance of 700 miles or six passengers 220 miles operating from 2,500 ft runways and cruising at 460 mph. Empty weight was 4,500 lb, takeoff weight 7,000 lb, wing span 37.5 ft, wing area 140 sq ft, and length 34.5 ft.

Designed to replace ageing Ansons, Doves and Pembrokes, the project did



The B.114 — general arrangement.

not arouse sufficient interest, so it and a follow-up design, the B.120, were abandoned, to bring to an end at Brough consideration of this class of aircraft.

Military Freighter Aircraft:

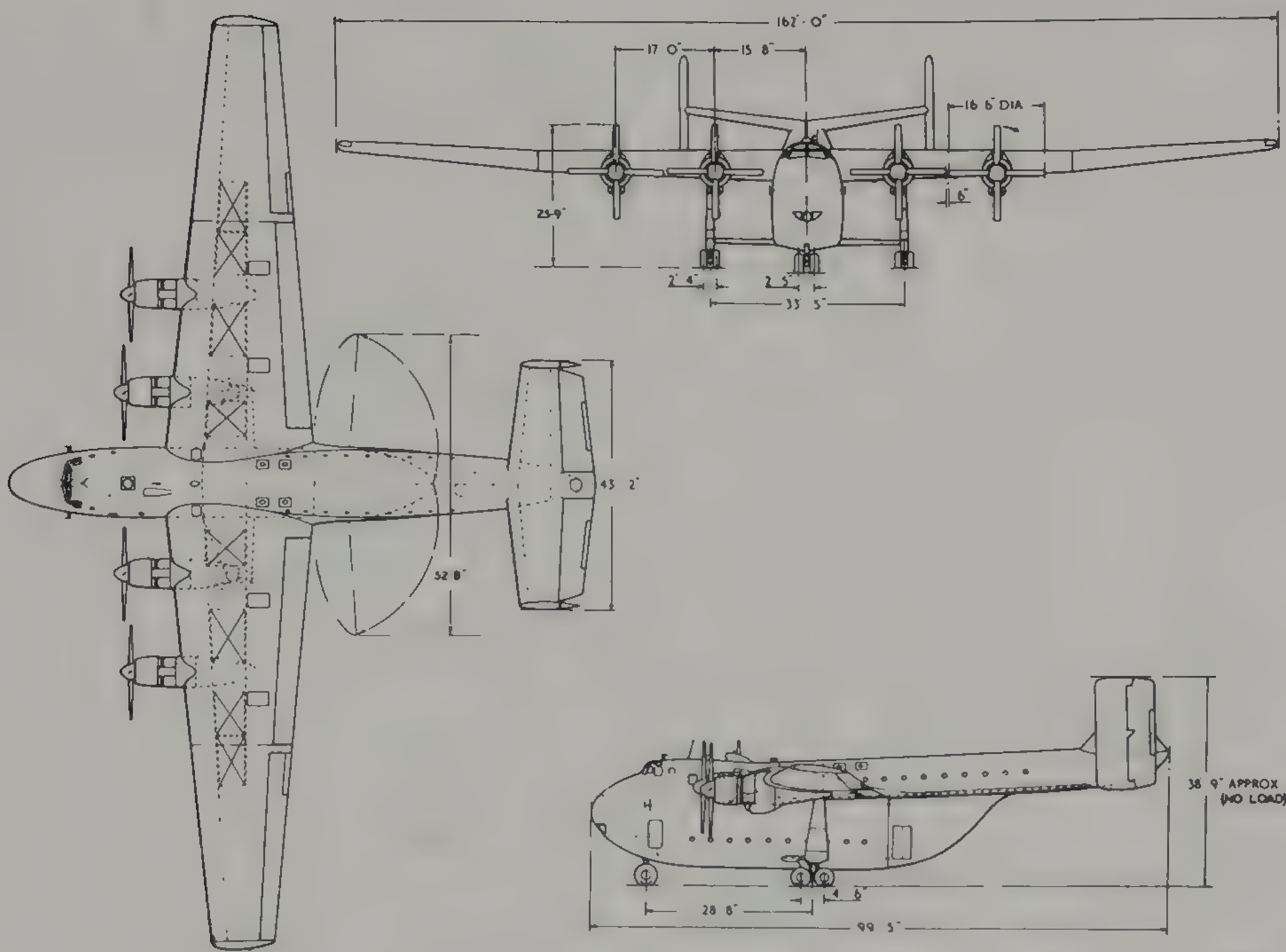
The Beverley and Variants

In the early 1950s development work at Brough was concentrated on the Beverley for the Royal Air Force with its primary role to support the Army in the field. The Future Project Office had little part to play in this, but gave backing to the efforts to sell a civil derivative. These were all abortive, although in late 1955 one Beverley under temporary civil registration did airlift some heavy oil drilling equipment to a site in the Middle East which was otherwise inaccessible, giving a clear demonstration of the possibilities.

The prototype powered with Hercules engines, WF 320, flew in June 1950, to be followed by the Centaurus-engined prototype, WZ 889, in June 1953. The first production Beverley, XB 259, flew in January 1955 and the type started active service with 47 Squadron in early 1956, by which time work at Brough was beginning to concentrate on the B.103, later the Buccaneer.

However, one major task associated with the proposed civil variant of the Beverley was, during this period, based in the Project Office, masterminded by Harold Brumby. Silver City Airways were at that time operating a cross-Channel car ferry with Bristol 170 aircraft, carrying two or three cars, their passengers being accommodated in a compartment at the rear. They showed interest in a larger-capacity and longer-range vehicle in the form of an adaptation of the civil counterpart of the Beverley, known as the Universal.

The proposed solution carried 42 passengers in the tail boom, which we had designed for troop transport or for parachutists who would exit through a hatch in the floor at the forward end of the boom. Six cars and five motorcycles could be accommodated as shown in the 40 ft by 10 ft by 10 ft hold, with some overlap at each end. The principle was to load alternately upper and lower levels of a



B.101

The Beverley — general arrangement.

two-tier arrangement, the wheels of each car on the upper level resting in a sling supported by two cross tubes mounted with rollers in side rails running the length of the hold. An electrically driven screwjack lift hoisted the car up to rail level, when it was pushed forward to the appropriate point along the rails and then locked. To prove this concept a full scale mock up was constructed with a commercially available Laycock car lift. 'Volunteers' from the office staff allowed their cars to be used as guinea pigs, although by no means all were willing to lend their prized possession for this purpose. The whole idea worked very well, and was given a thorough testing over many hours. The concept finally came to nought, but the work provided an interesting diversion.

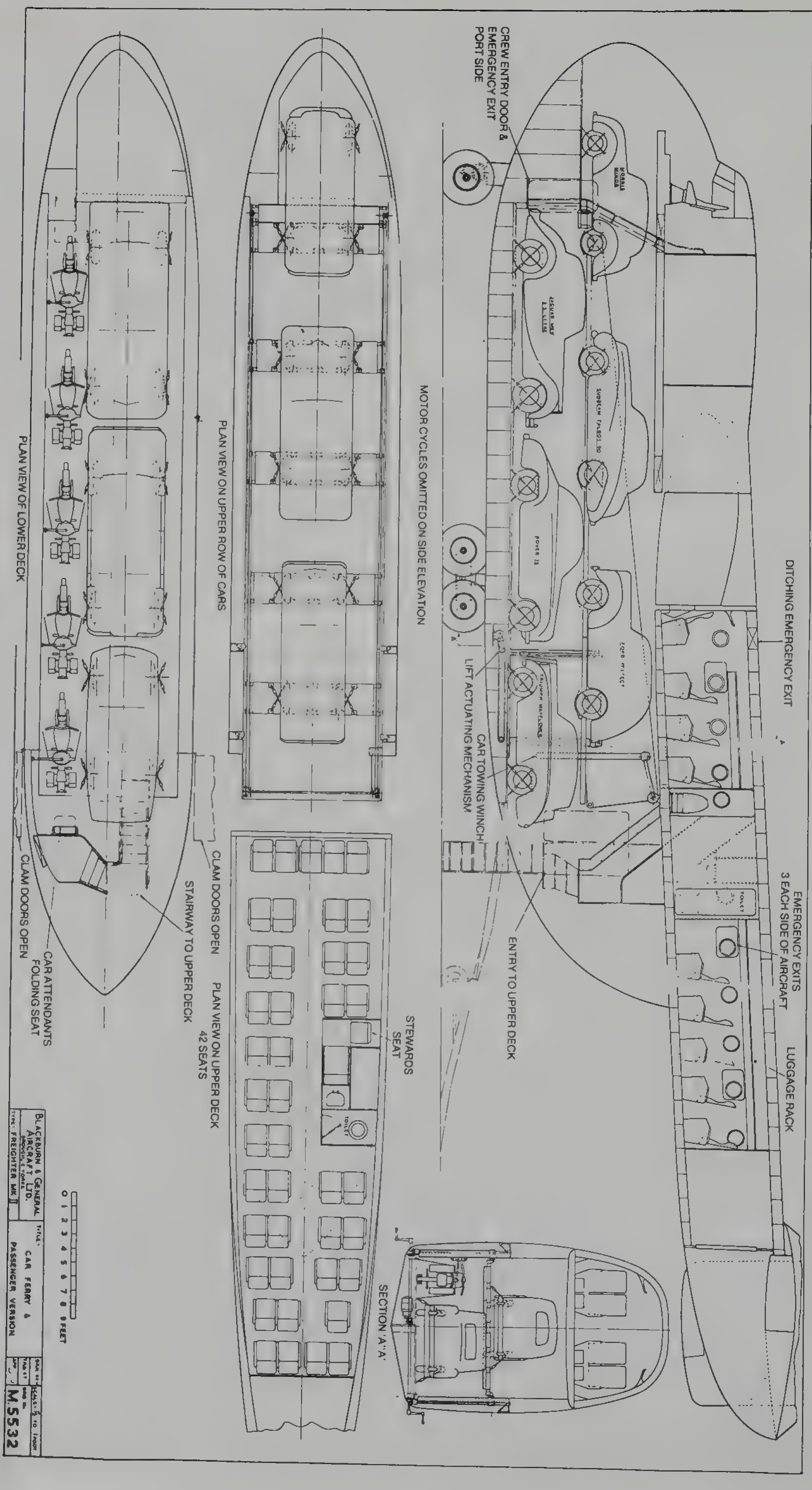
B.104 Military Transport

In 1955-56 I moved from Brough to accommodation in the newly established London Design Office, to form an independent Future Projects Office. Whilst I was there, the major task was to respond to military Operational Requirement 323 for a medium-range and medium-sized freighter.

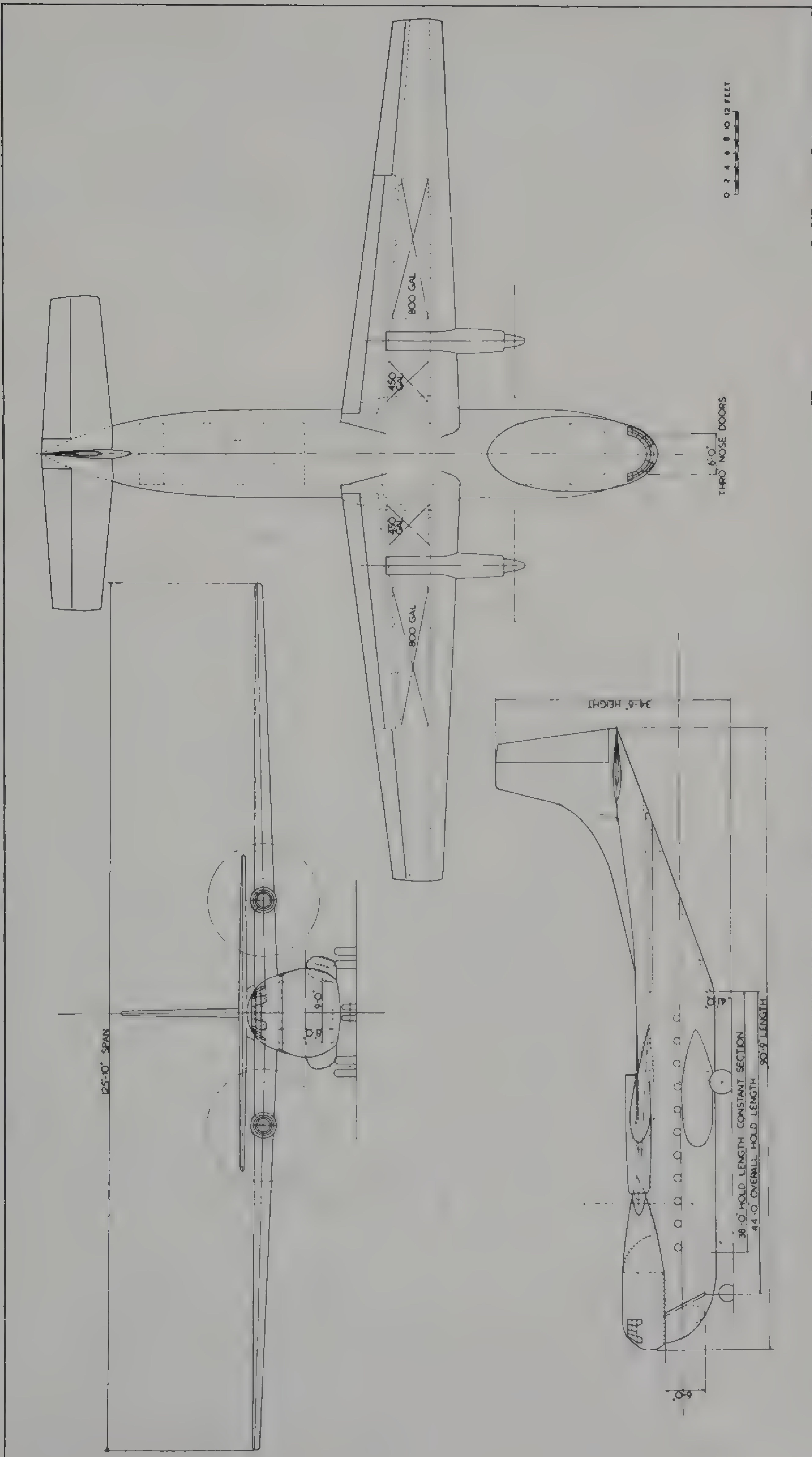
I had always had doubts of the concept of the Beverley, with its ancestry clearly with the Hamilcar glider. I felt that a pressurized, turboprop-powered configuration with a retractable undercarriage had far better prospects. This view is, of course, borne out by the 36 years of success of the Lockheed C-130.

The B.104 was investigated both as a military aircraft to meet OR 323 and also for possible civil application. It had a fuselage cross-section based on the same principle as was used on the Ambassador: two circular arcs joining at floor-level.

The design was based on two 4,400 hp Rolls-Royce Tynes, had a wing area of 1,600 sq ft, span of 126 ft, and overall length of 91 ft. With loading doors at



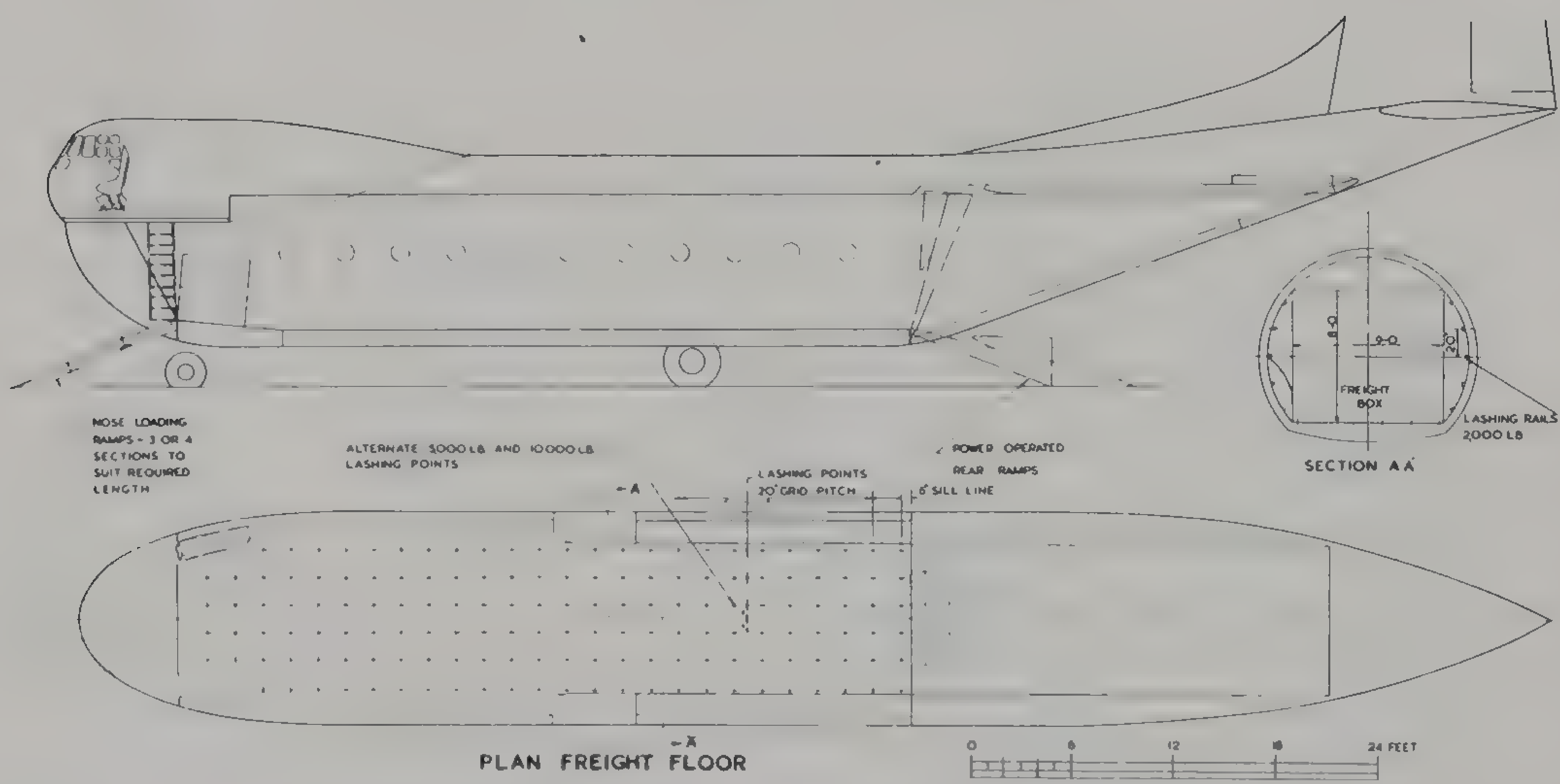
The Universal car ferry.



The B.104 — general arrangement.

both front and rear, the latter being suitable for heavy dropping in flight, the freight compartment was 38 ft long, 9 ft wide and 8 ft high. With a basic weight of 35,200 lb, and take off weight of 62,500 lb, cruising at 315 mph at 20,000 ft, a payload of 20,000 lb could be carried for a stage of 700 miles and 10,000 lb for 2,000 miles using a 900 yard (2,700 ft) runway.

There was an alternative design with four Rolls-Royce Darts, but this was heavier, and the two-Tyne solution was preferred. The design was submitted to the Ministry but was not accepted, the role being later met by the (to some extent privately developed) Armstrong Whitworth Argosy.



The B.104 — internal arrangement of freight compartment.

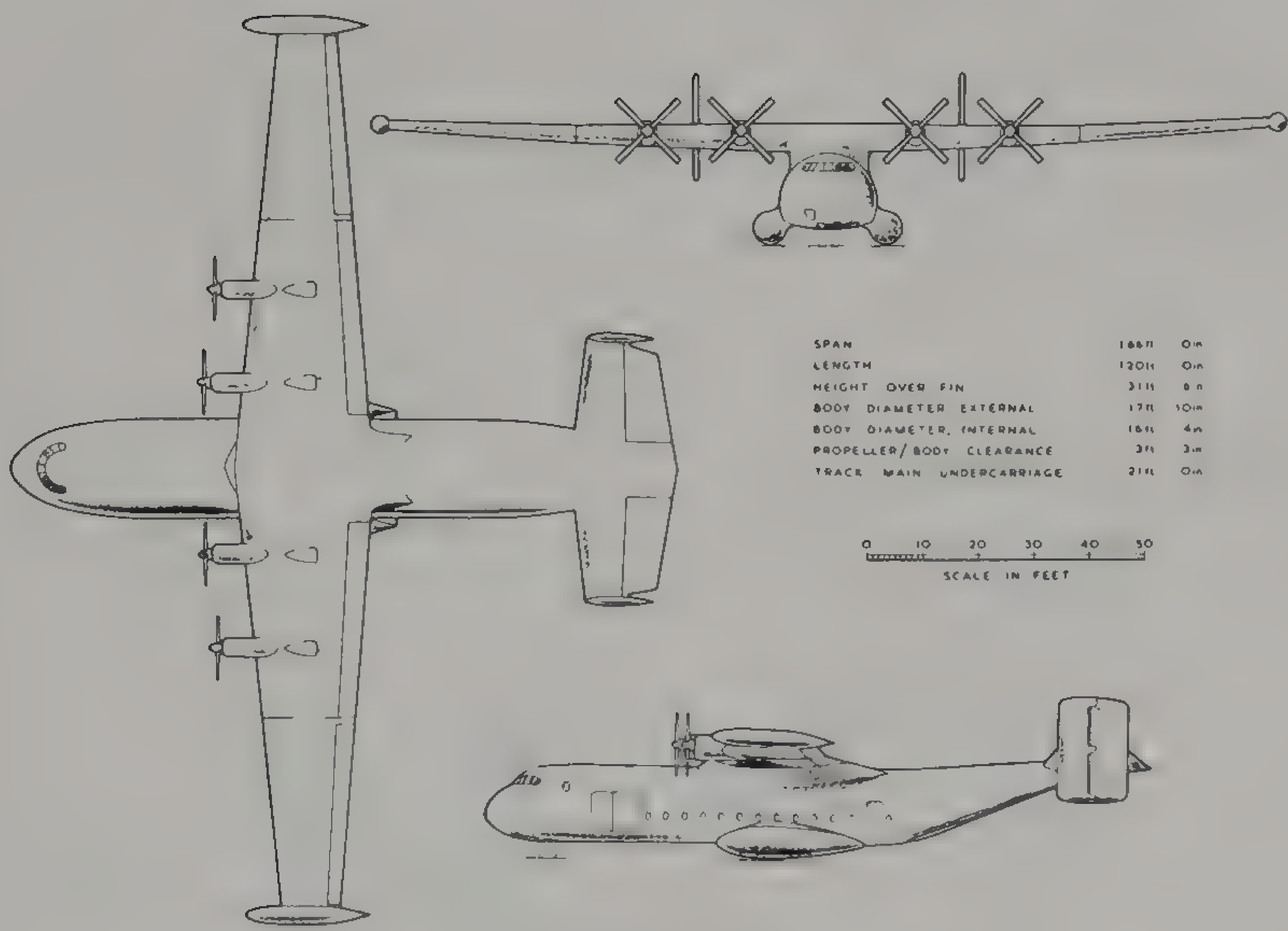
B.107 Tactical and Strategic Freighter

As a follow up to the B.104 design, work was started to apply some of the principles evolved to develop the Beverley for a wider application. Possible turboprop engines were, as first choice, the projected Bristol BE.25 Orion, with the Rolls-Royce Tyne as alternative.

The aim was to produce a freight aircraft of genuine strategic capability, but at the same time one which could, operating at reduced weight, emulate the range/payload and short-airfield performance of the existing Beverely. The result was the B.107, illustrated, which retained the wings and tail unit of the Beverley, but with the Centaurus engines replaced by turboprops. The new fuselage had a hold 60 ft long, 11 ft high, and 12 ft wide at floor level. Maximum payload was 58,000 lb, and maximum range about 4,500 miles, still with a 20,000 lb payload.

Compared with the Beverley, cruising speed was increased from 175 to 355 mph, basic weight from 79,000 lb to 89,000 lb, and takeoff weight from 135,000 lb to 175,000 lb. Even at this higher weight, balanced field length required was only 10 per cent greater than for the Beverley, and a typical payload of, say, 40,000 lb could be carried three-and-a-half times as far.

As work proceeded on the B.107 in 1956-57 it became increasingly obvious that the B.103 work would leave no room for its conclusion. It was therefore



The B.107 — general arrangement.

proposed to seek a collaborator to design and build the B.107 fuselage for marrying to the Brough-produced empennage and wings. The proceedings were brought to an abrupt halt when it was announced that an order had been placed with Shorts for an aircraft which in many ways looked similar to the B.107 but was based on using the wings and empennage of the Britannia. By the time that the Britannic (later renamed the Belfast) had matured, Government policy had changed to the point that there was no longer a need for a strategic freight transport. Thus only few were built. Even these became surplus to Royal Air Force requirements in a relatively short time, although three of these operating as Heavylift Airlines are providing a useful service on a world-wide basis.

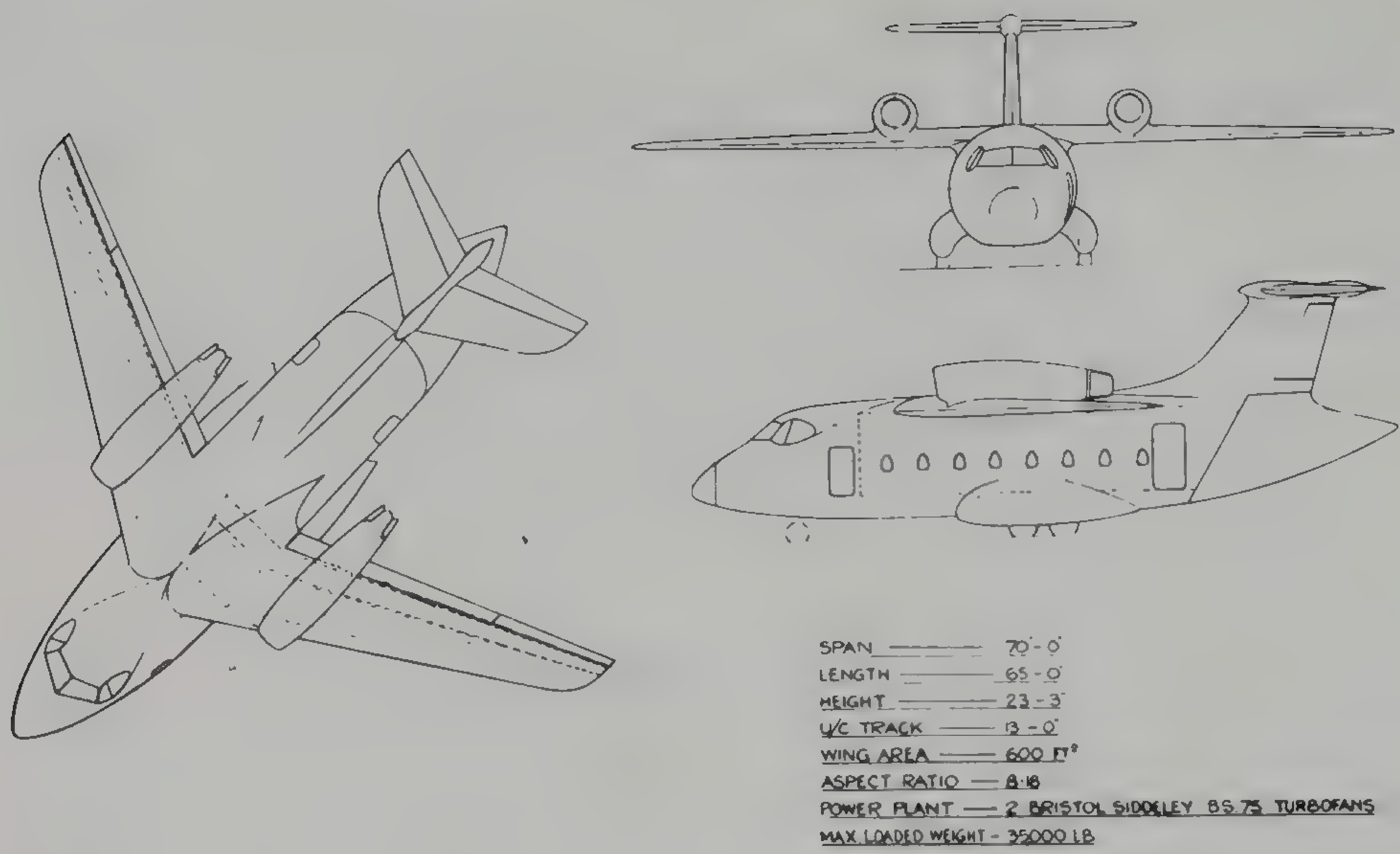
The B.107 would have had one big advantage over the Belfast in at least the military role, as with some 50 per cent more wing area its short-field capability would have been considerably superior. As things turned out, the B.103 was much better business for Brough than the B.107 would have been, which makes up for the disappointment felt at the time.

B.122 and B.125 Freighters

In the early 1960s, still as the doyen of freighter aircraft, Charles Prower turned out two interesting and advanced concepts in the B.122 and B.125, shortly before the Future Projects Office became fully under my control again in 1962.

The B.122 was designed, as was the previous B.114, to use the principle of the cold jet flap to enhance airfield performance whilst retaining the higher cruising speeds available with jet propulsion. It had a basic weight of 20,000 lb and a takeoff weight of 35,000 lb. Wing area was 600 sq ft, span 70 ft and thickness/chord ratio 15 per cent with 30° sweepback. Aircraft length was 65 ft, with the freight compartment 31 ft long, 8.5 ft wide and 7 ft high. Rear loading doors of the faired rear fuselage deflected sideways and upwards — a similar but simpler arrangement than that which had been proposed for the B.104.

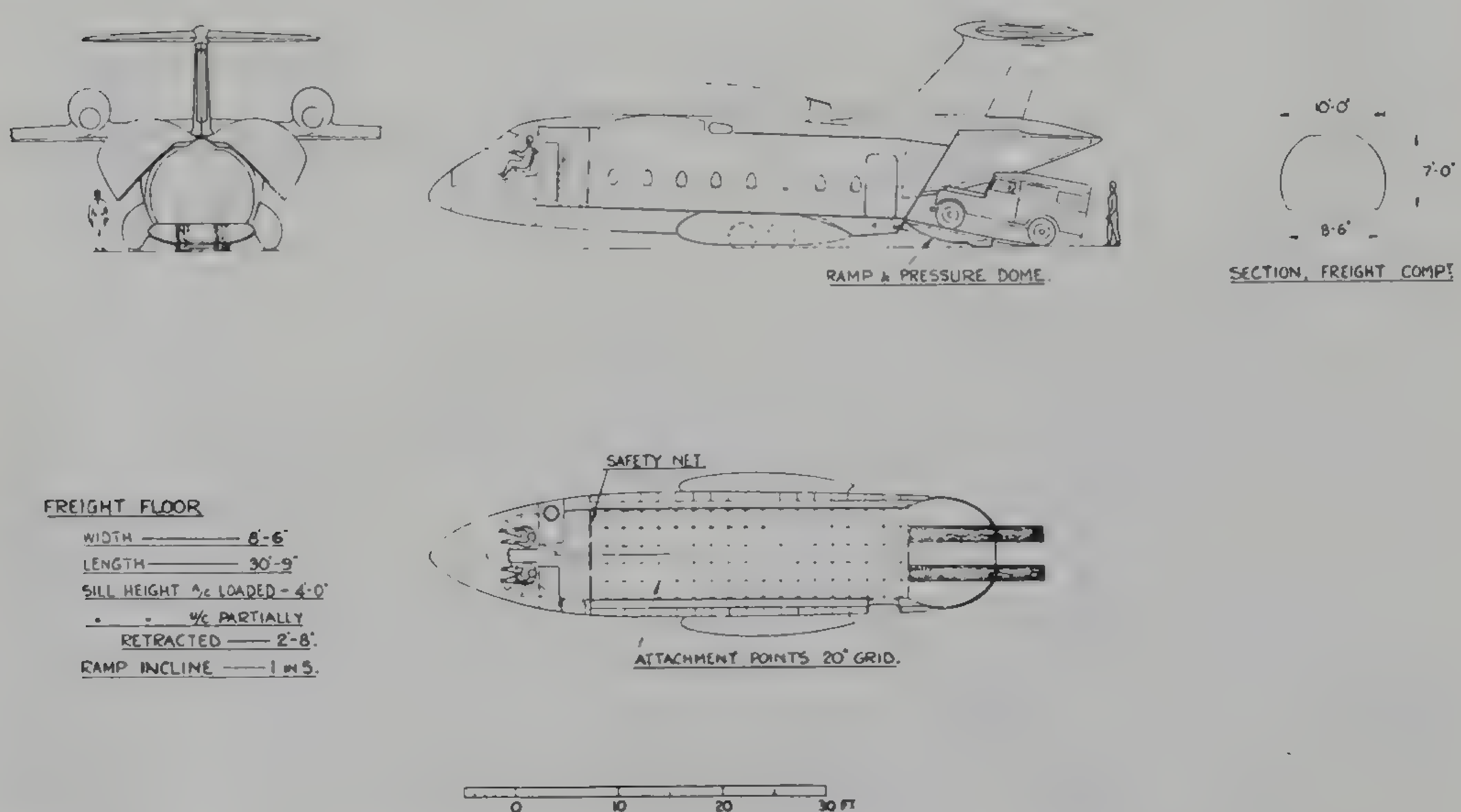
The engines were to be two 7,350 lb Bristol Siddeley BS.75 turbofans



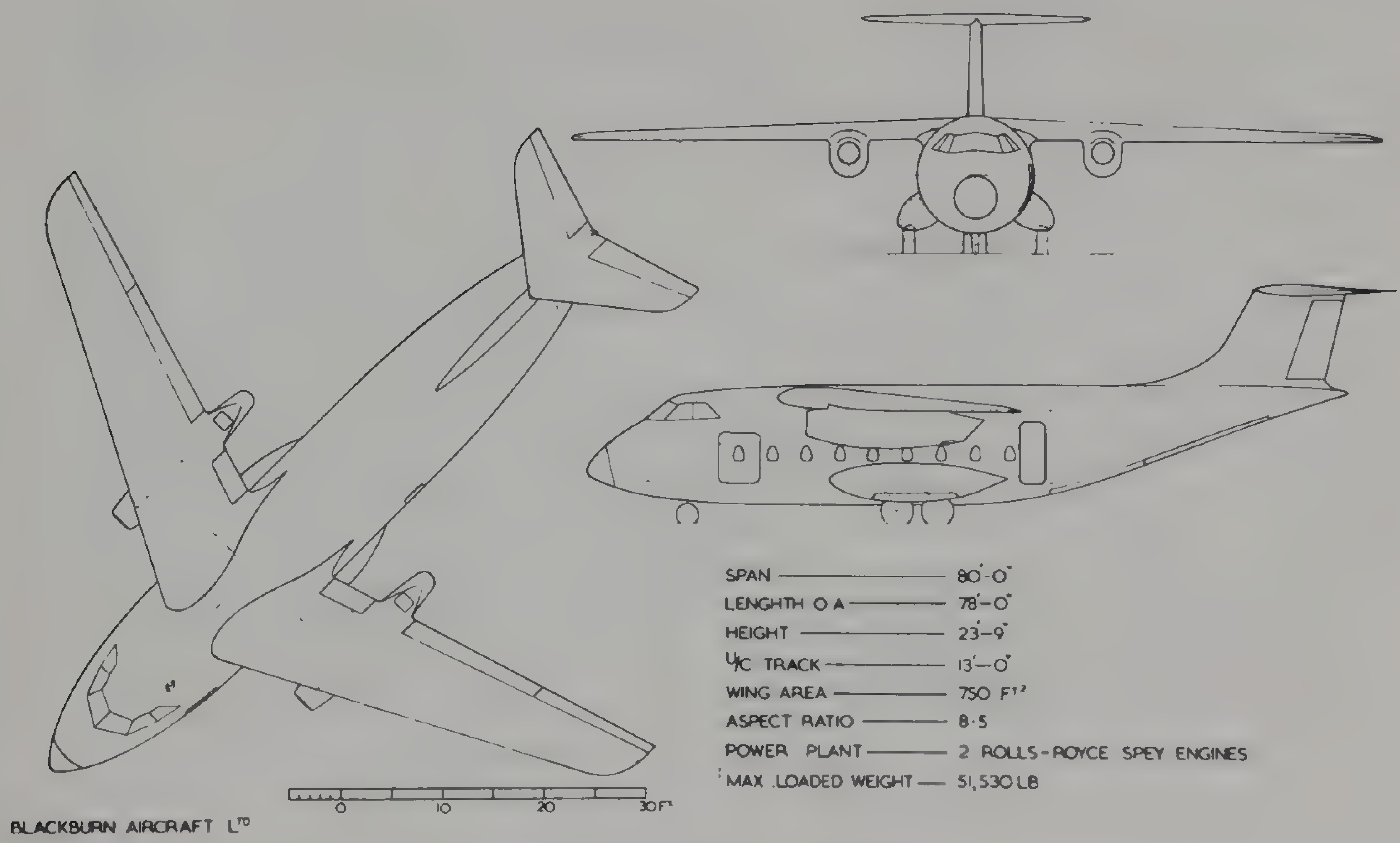
The B.122 — general arrangement.

mounted over the wing. Fan air was ducted and blown over the nose radius of the 15 per cent chord full-span flaps, which were deflected 50° for take-off and 70° for landing. The B.122 had a cruising speed of 480 mph, and could carry a payload of 10,000 lb, over a stage of 480 miles or 6,000 lb for 1,400 miles, operating from a 2,000 ft strip. Stalling speed at maximum landing weight of 33,500 lb was only 68 mph.

An advanced concept for its time, the B.122, like many other projects, was aimed at taking over duties currently performed by the Dakota, but it got no



The B.122 — freight compartment and loading ramp.



The B.125 — general arrangement.

further than the Project Office. Many years later the same idea, in an identical layout, was used in the Boeing YC-14 and Antonov 72 and 74.

It so happened that at this time knowledge was gleaned of a possible NATO requirement for a STOL Assault Transport Aircraft, and an enlarged version of the B.122 but with features specific to this role was designed as the B.125.

This aircraft had a basic weight of 26,000 lb and takeoff weight of 51,500 lb. Wing area was 750 sq ft, span 80 ft, sweepback of the 15 per cent thick wing 25° and overall length 78 ft. Power plants were to be two underwing-mounted Rolls-Royce Speys of 10,400 lb thrust. Freight-compartment dimensions were 30 ft long, 7.25 ft high, and 7.25 ft wide. The more conventional beaver tail and ramp-type doors were proposed, on account of airborne dropping needs.

A payload of 12,000 lb could be carried over a stage of 1,600 miles at a cruising speed of 460 mph. At maximum weight takeoff distance was 2,000 ft; but a useful mission could be accomplished with an 1,100 ft takeoff. Landing distance was only 600 ft and stalling speed a mere 66 mph.

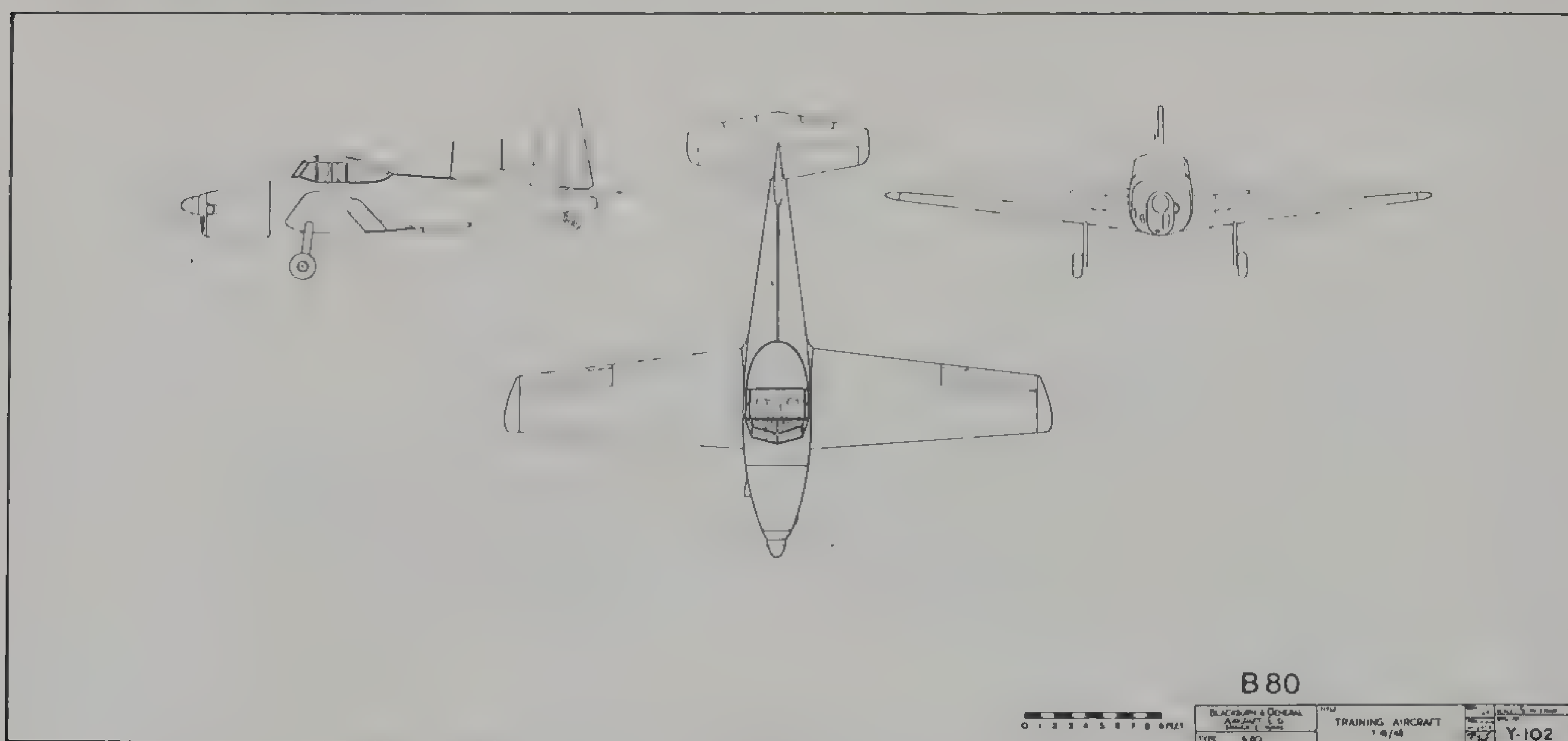
Compared with contemporary designs the concept was ambitious, and may well have been too much so. It would also appear that the aircraft was undersized for missions which have arisen during the period when it would have been in service. In any case it remained a paper aircraft, and one which saw the end of transport aircraft design at Brough.

Basic trainers, B.80, B.92, P.147 and P.164

Brough has over many decades retained an active interest in the primary training function. From 1935 to 1950 No.4 EFTS et seq. was based at Brough, and many senior RAF officers learned to fly there.

In 1932 Blackburn produced the B.2 trainer. Unlike the more famous Tiger Moth it had side-by-side seating and an all-metal fuselage. One is still flying today, and is in demand for flying displays. In 1948-54 125 Percival Prentices and 30 Boulton Paul Balliols were built in the Brough factory.

My first task on joining the Brough Project Office was, under the supervision of Roy Ewans, to prepare a submission for a new basic trainer for the Royal Air Force to Specification T.16/48. The result was the B.80. Ewans insisted on using the 250 hp unsupercharged Gipsy Queen 30 engine. I had always understood that an important characteristic of a basic trainer is to have a good rate of climb up to operating height, and therefore pressed for the 295 hp supercharged Gipsy Queen 50. Memory is hazy, and all records have since been destroyed, but I believe that a compromise was reached in which both were offered as alternatives. The submissions which were selected for flight evaluation were the Handley Page and Percival designs. With airframes virtually indentical to that of the B.80, these were offered with the 375 hp Armstrong Siddeley Cheetah, and the finally successful contender, the Percival Provost, went into service with the 550 hp Alvis Leonides!



The B.80 — general arrangement.

Following the signing of the agreement with Turbomeca, one of the engines of interest was the Marboré turbojet of 880-1,000 lb thrust. With the front-line strength of the Royal Air Force now mainly gas turbine powered and with a suitable engine now available, proposals were made for a twin-Marboré basic trainer, the B.92, of which no other data remain. The proposal drew no response so, like many other Project Office ideas, it was abandoned. What a contrast with the USAF, whose initial pilot trainer for 35 years has been twin-Marboré powered!

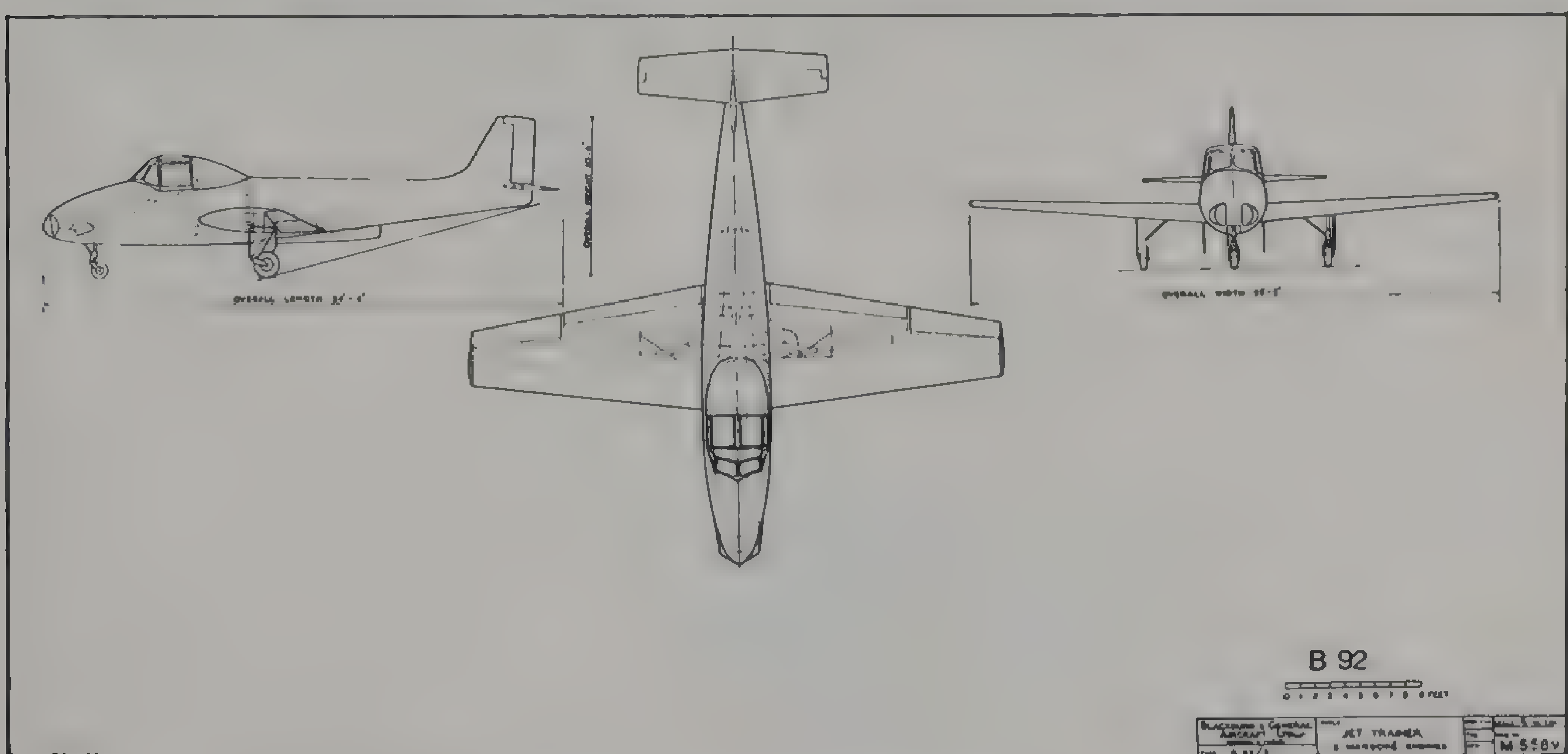
It was not until 1967 that a trainer design was again worked on. This was as a result of a paper issued by the Central Flying School, outlining their thoughts for a new basic trainer. This paper specified a preference for turboprop propulsion, an integrated instrument display system similar to that in the new front-line aircraft, with navaids to be compatible with ICAO requirements, and a new integrated non-ejection seat and parachute harness. An approach speed of 70 mph, cruising speed of 140-170 mph, and an endurance of 4 hours were

suggested, together with a high rate of climb. Plastic construction was to be considered.

The P.147 emerged from our studies of these proposals, together with the following comments:

(i) At the current state of the art, simple all-metal construction was preferable to embarking on plastic solutions.
(ii) A 300 hp turbocharged Rolls-Royce Continental TS10-520E piston engine was a far better proposition than any known turboprop. Possible turboprops fell into 300 and 500 hp brackets. The former would have a much inferior climb to altitude, whilst the latter would be overpowered at low altitude and even more expensive.
(iii) A retractable undercarriage was favoured, in contrast to the CFS preference for the fixed type.
(iv) The CFS proposals for an integrated flight instrument display, the proposed navaid fit and the integrated seat and parachute harness would involve costs which it would be difficult to sustain.

The P.147 had a basic weight of 2,400 lb, and a takeoff weight of 3,250 lb.



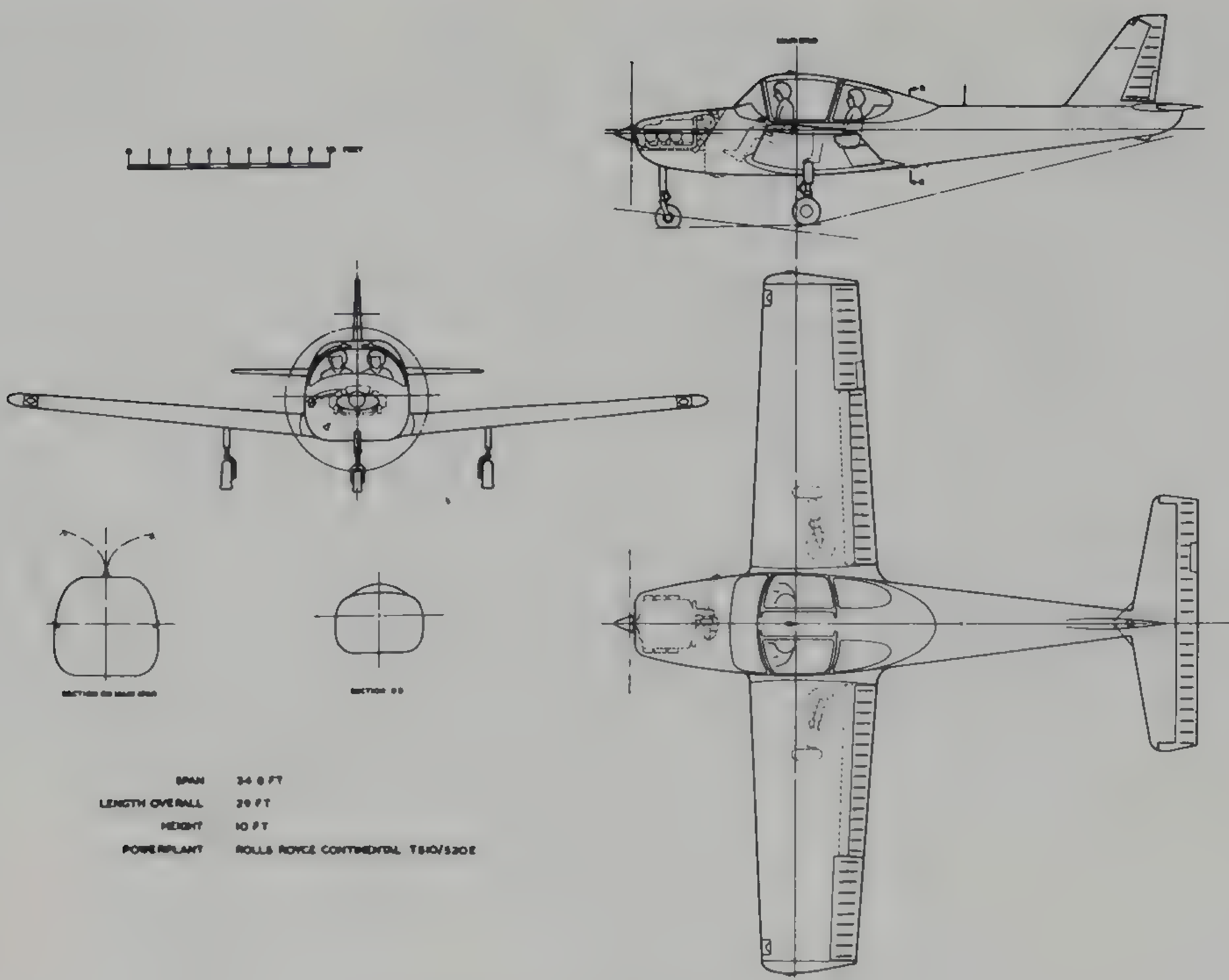
The B.92 — general arrangement.

Wing area was 195 sq ft, span 35 ft and length 29 ft. An endurance of 4½ hours and a cruising speed of 160 mph was quoted.

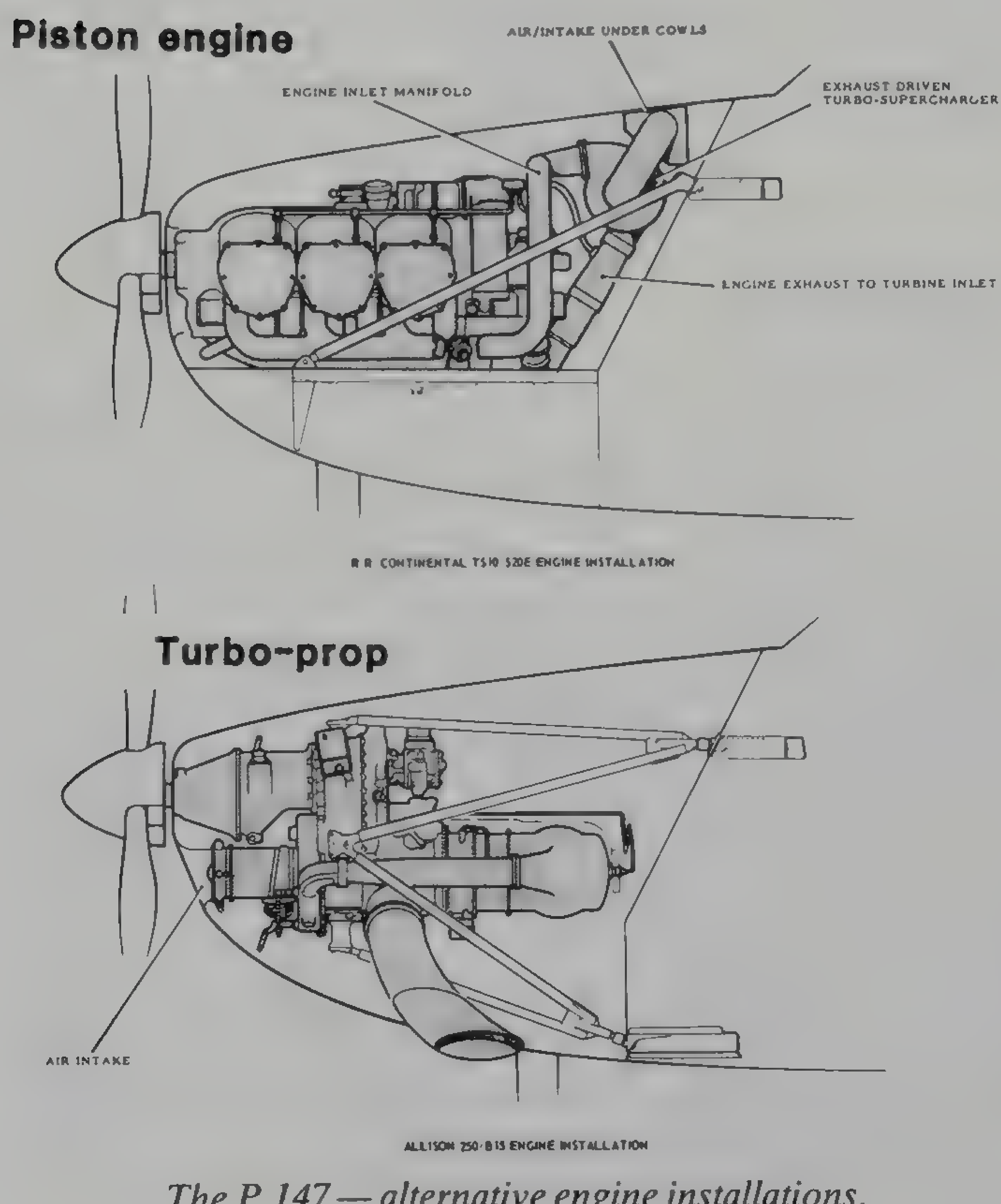
It did not appear economical to operate such an aircraft as a replacement for the Chipmunk, for which an adaptation of the Beagle Pup was suggested (later to appear as the Bulldog), but it did seem that it could usefully and economically cover the Royal Air Force training syllabus up to and including that part then undertaken by the Jet Provost 3. As was expected, there being no firm requirement, nothing came of the P.147, and it was to be some 12 years before the topic came up again.

For the record, in connection with trainers, a substantial design and manufacturing effort was mounted at Brough in support of Kingston on the Hawk programme, leading eventually to the transfer there of the design authority of the two-seat trainer versions of the Hawk.

Interest in basic trainers was revived in the 1970s when the RAF started



The P.147 — general arrangement.



The P.147 — alternative engine installations.

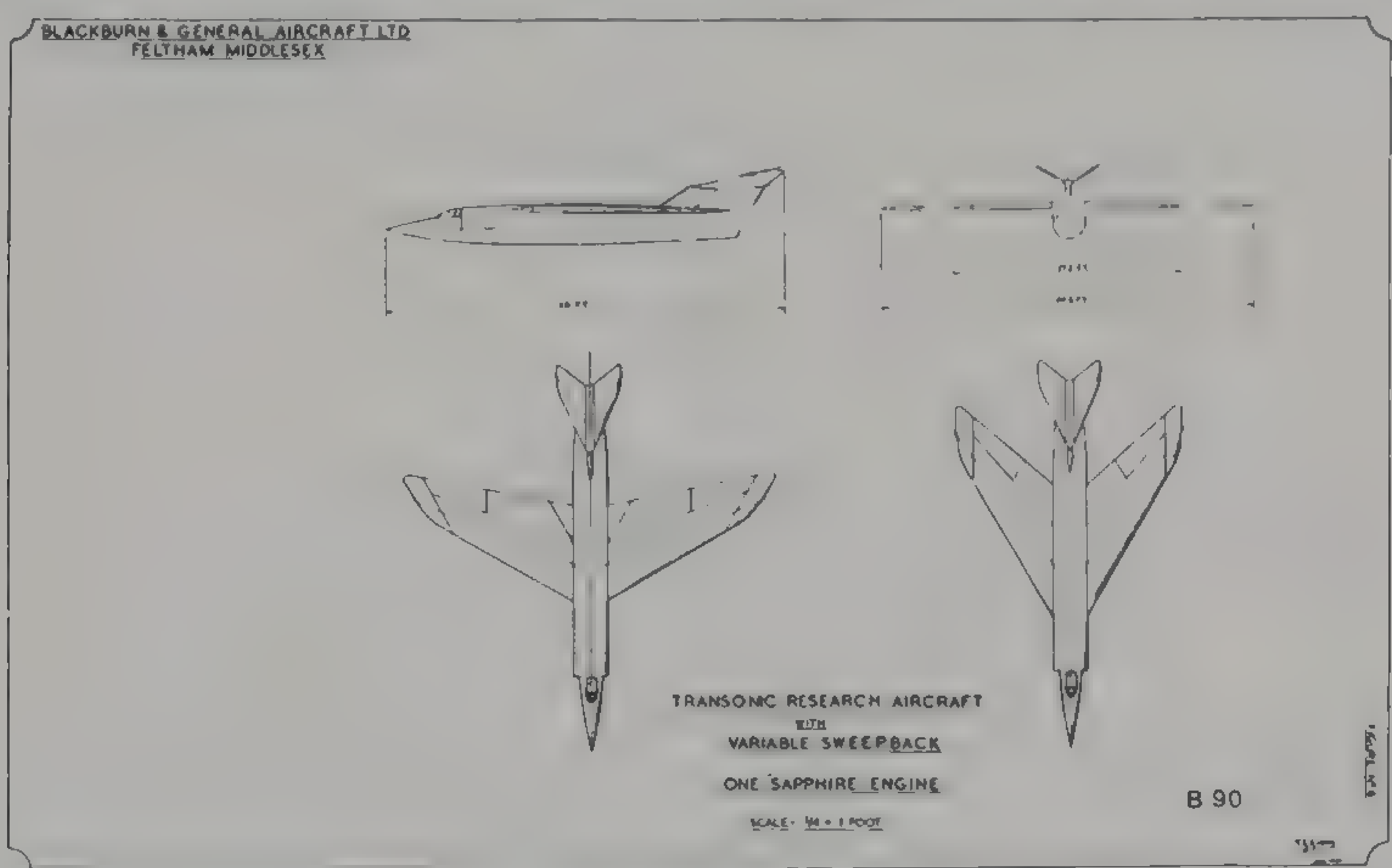
to show intentions of purchasing a new aircraft for this purpose. Initially an indigenous design, the P.164 was offered in both jet and turboprop forms, to be followed by a joint venture with the Swiss Company, Pilatus, to supply, modified where necessary, the Pilatus PC.9. Whilst the decision for this particular application went in favour of another joint venture, between Shorts and the Brazilian company Embraer, the Brough-Pilatus combine is supplying modified PC.9s against an order from Saudi Arabia, thus retaining active interest in basic trainers at Brough for the foreseeable future.

A Miscellany of Combat Aircraft

B.90 Experimental Supersonic Aircraft

Dating from 1950, B.90 was the designation given to a General Aircraft design, following the transfer of work and personnel from Feltham. The brainchild of Tom Guppy, it was in response to a requirement for a research aircraft to explore supersonic flight with the possibility of subsequent adaptation for a fighter version.

Powered by an Armstrong Siddeley Sapphire turbojet, and with a thin wing whose characteristics were at that time clouded with uncertainty, it also embraced the principle of variable sweepback. Unlike the current concept of a



The B.90 — general arrangement.

fixed pivot, variable sweep was obtained with a translating mechanism with flip-up/flip-down fairings at the bodyside. A working model of this could still be found in the Project Office over 30 years later.

There existed considerable uncertainty on the nature of the drag rise above a Mach Number of 1.0, such that the predicted maximum speed could lie anywhere between 1.2 and 2.0. If the former were to be the case the value of the variable sweepback would be negligible. The B.90 was very advanced and ambitious, but it did not proceed, the order going to English Electric for their P.1, which led to the Lightning.

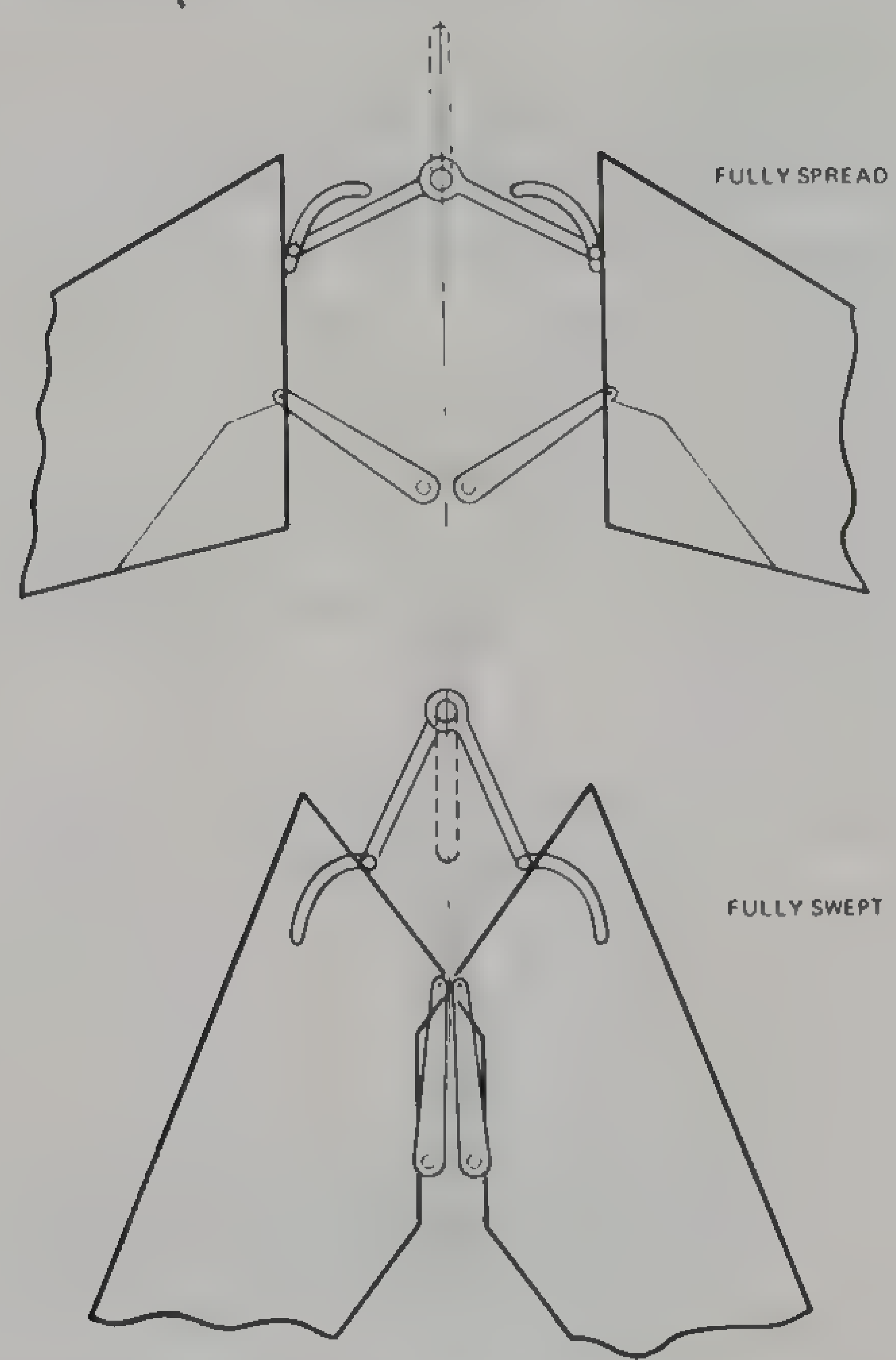
B.97 Rocket Interceptor

In early 1952 we studied specification F.138D for an interceptor fighter to combat high-flying subsonic bombers. As written, the specification put emphasis

on a very rapid climb to an altitude of around 50,000 ft. This was to be effected using a bifuel rocket engine. On reaching operational altitude the aircraft would turn into a firing position and make its attack. Then, after an unpowered glide home, it would make a deadstick landing.

Two suitable rocket motors were offered. The de Havilland Spectre of 8,000 lb thrust used HTP (high-test peroxide) as the oxidant, while the Armstrong Siddeley Screamer of the same thrust used liquid oxygen, in both cases kerosene being the fuel.

Unfortunately, the decision at Brough to make a submission was made only eight weeks before the proposals had to be in, which, to say the least, meant a

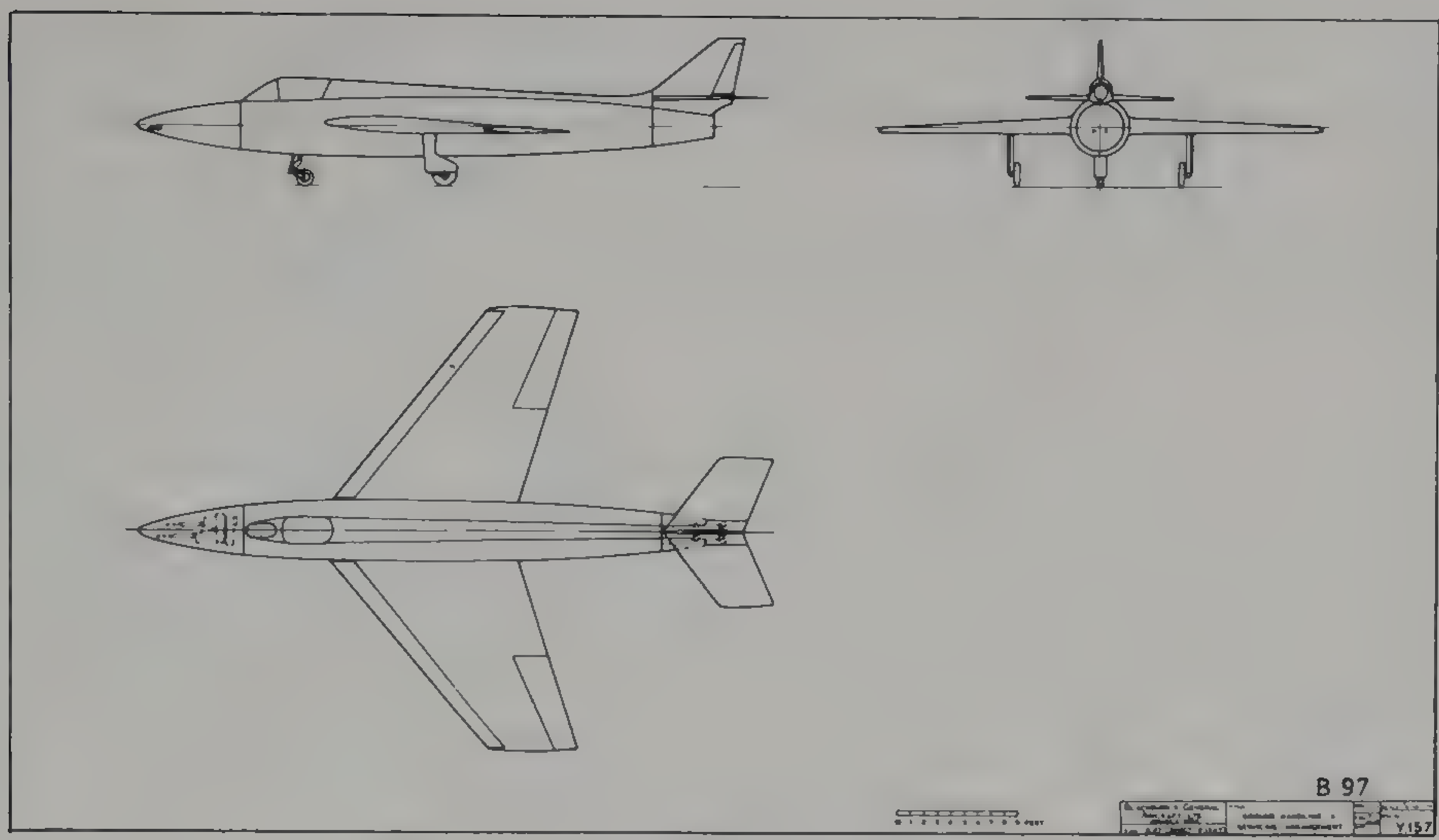


The B.90 — wing sweep mechanism.

rapid response. In studying the specification I made two basic decisions, one of which turned out to be bad and the other good, at least in principle. As I saw it, the climb would be made at subsonic speed and combat turning for interception likewise, by which time the aircraft would be out of fuel. Therefore, ultra-thin wings needed for supersonic flight and which were untried constituted a needless luxury and risk. An 8 per cent thick wing with a modest sweep of 35° seemed to be a low-risk venture and would not hamper the operation of the aircraft.

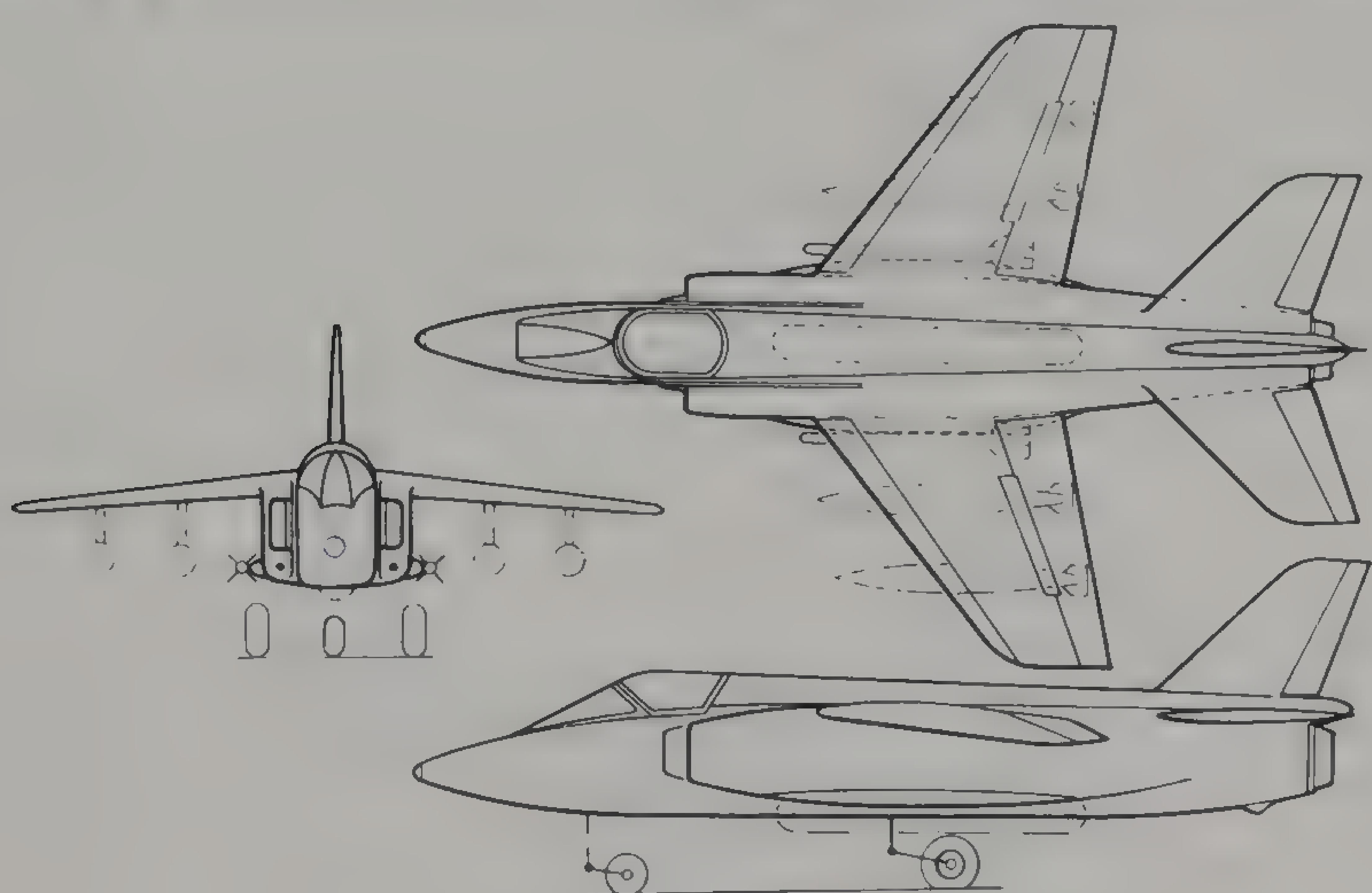
The thought of an unpowered approach and deadstick landing did not appeal at all, and it also seemed to be sensible to have power available to drive the aircraft accessories. A small gas turbine of the correct size seemed to be a good solution, so we included a 1,000 lb-thrust Turbomeca Marboré in our proposals. With ink barely dry and pencil dust still rising, the submission went in.

The sequel was not without interest. The timescale was suddenly extended to allow a further submission to be made which was to include a gas turbine to supplement the rocket motor. As the B.97 already conformed to this we were excluded from a second submission, but could well have done with some extra time to consolidate our proposals.



The B.97 — general arrangement.

The final outcome was an order to Saunders-Roe for the SR.53, which included a 1,750 lb Armstrong Siddeley Viper turbojet in addition to the Spectre rocket. This did fly in prototype form, although a similar order placed on Avro with the Screamer rocket as primary power was cancelled before it flew. The SR.53 was a genuinely supersonic design and was followed by the more



The P.146, RB.172 — general arrangement.

advanced SR.177 which added an 8,000 lb thrust de Havilland Gyron Junior turbojet to the Spectre rocket, This in turn was cancelled following the notorious Duncan Sandys bombshell of 1957.

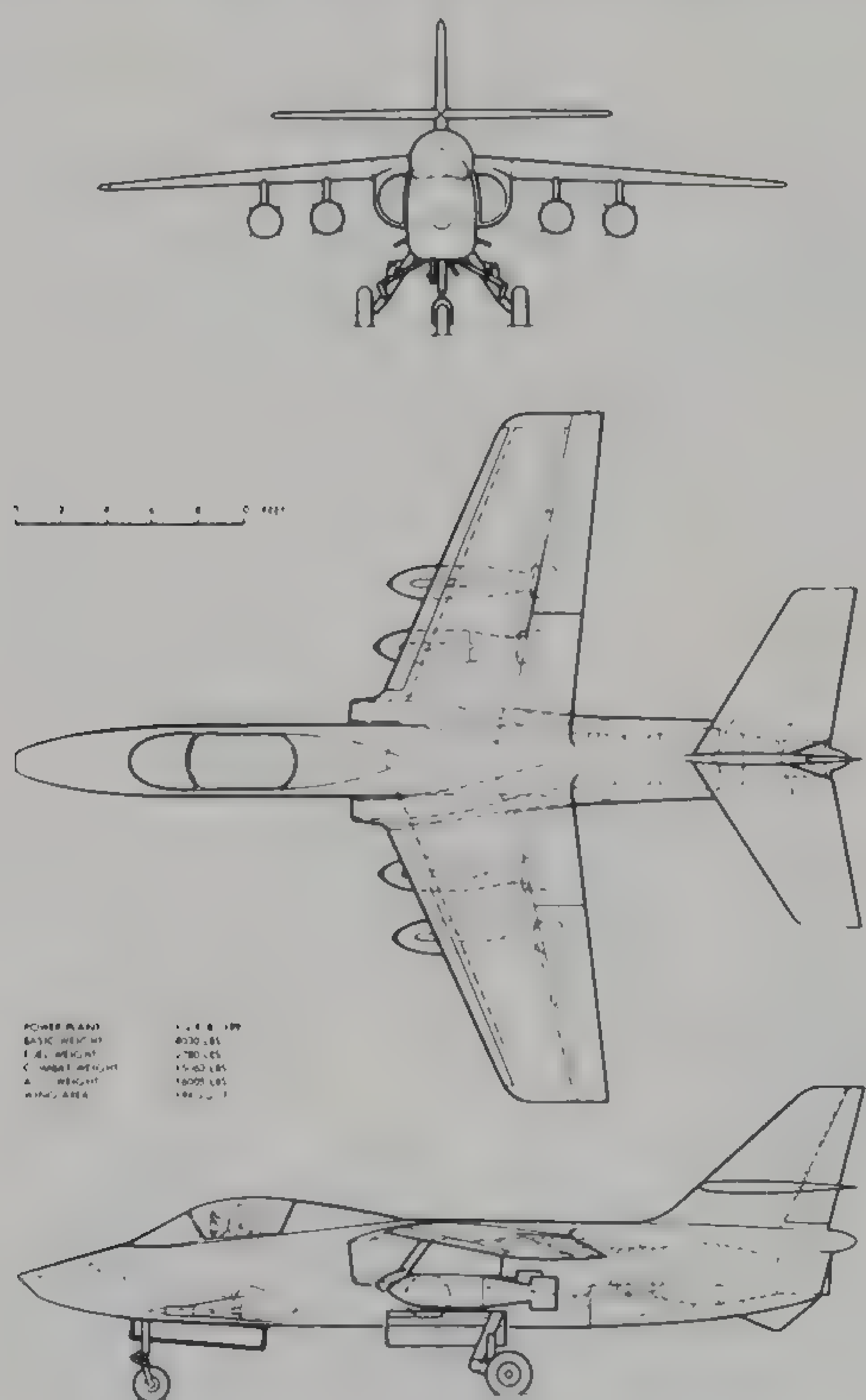
Light Ground Attack Aircraft

In 1967-71 a series of light ground attack aircraft were studied as a possible cheap way of satisfying one of the operational needs under discussion with the authorities. The first definitive design to emerge was the P.146. In an era where the Harrier had yet to prove itself, we thought that our experience of leading-

edge and trailing-edge flap blowing developed on the Buccaneer could be extended to give even higher lift coefficients, and hence a good STOL capability and thus find a reasonable market slot.

Powerplants considered were the Rolls-Royce Turbomeca Adour in both its unreheated form, giving some 5,000 lb of thrust, and reheated in the 7,000 to 8,000 lb bracket, and the RB.199 unreheated at 9,000 to 10,000 lb. Basic weights were in the 8,200 lb region, with takeoff weights of 15,000-18,000 lb.

The dry Adour was considered to give insufficient performance, so the choice lay between the reheated Adour and the dry RB.199. The latter showed distinct advantages, requiring only 40 per cent of the mission fuel and with the higher cruising thrust available was 20 per cent faster. As the study progressed it became obvious that the complications and cost of boundary-layer control were not justified, so one of our special features was abandoned. We settled for takeoff runs in the 2,000 to 3,000 ft band. Within this, the RB.199 gave runs 40



The P.154 — general arrangement.

per cent better than with the Adour. On the debit side it was estimated that the project would cost 30 per cent more to develop and 10 per cent more to produce than the Adour version.

The P.154 of 1971 was a step forward from the P.146. With a high wing to ease underwing stores carriage, and also for aerodynamic efficiency, basic weight was 7,500-8,000 lb, and takeoff weight 16,000-18,000 lb, depending upon the powerplant.

By this time the Harrier, at one end of the scale, had proved itself in service and become firmly established. At the other end, the P.1182 Hawk trainer programme had been firmly launched. The latter, in spite of a difference of

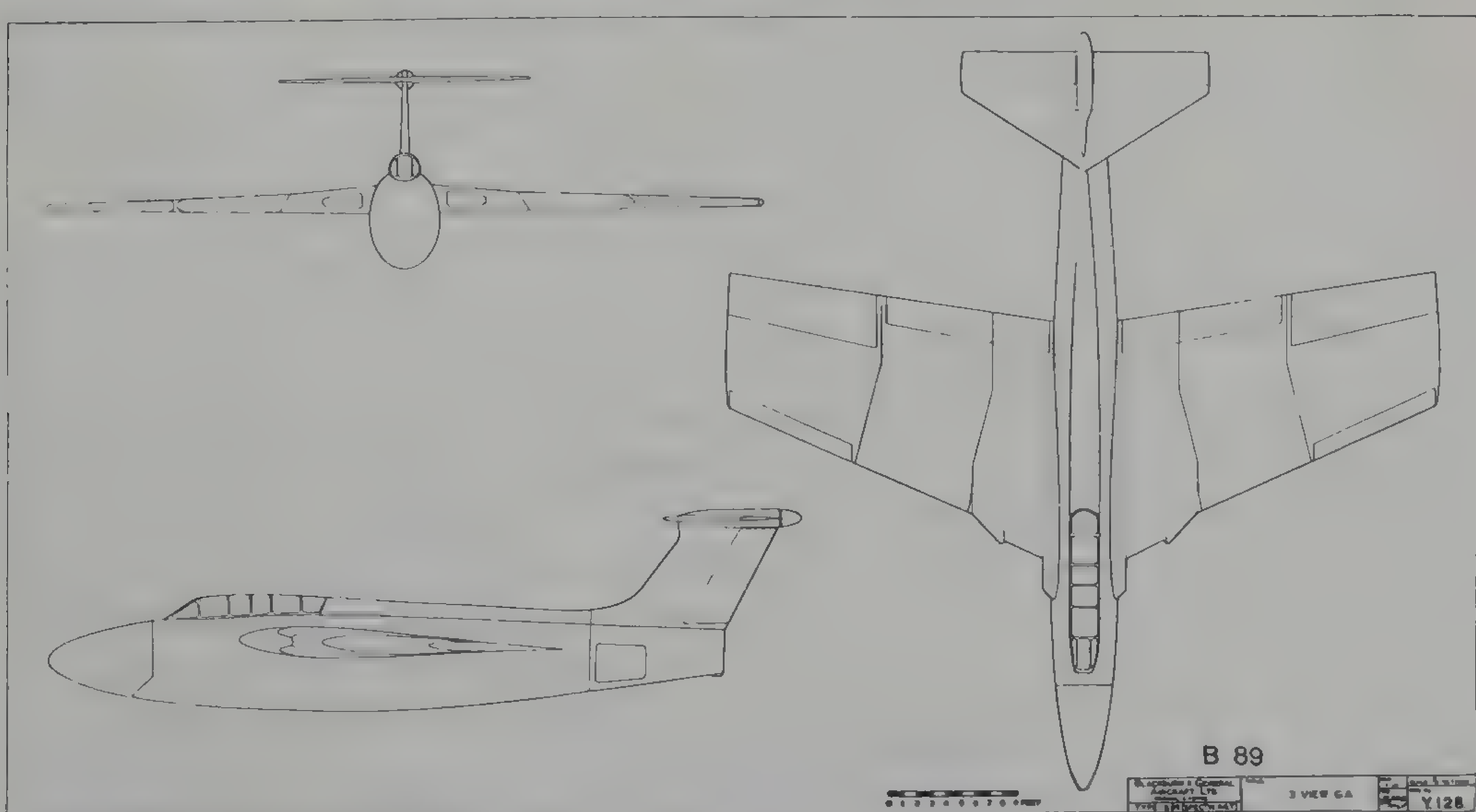
opinion between Kingston and Brough on wing and intake positions, clearly had the potential for development into a useful light ground attack aircraft, such that development of an additional type could not be justified and the work was terminated.

Much of the thinking which had been put into these studies led naturally into considerations of a high-performance lightweight fighter which became a prime topic over the next 14 years.

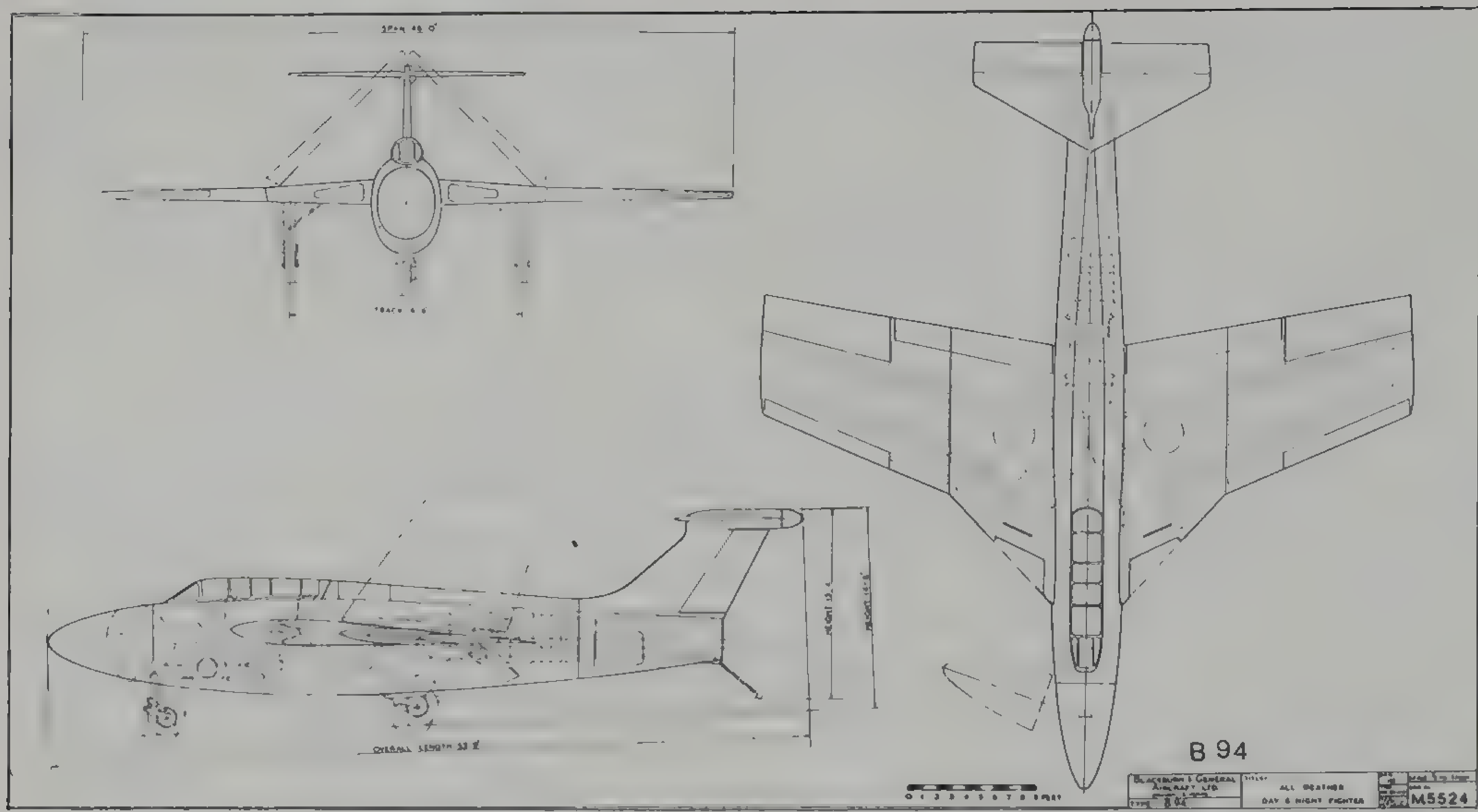
Naval Fighters, B.82, B.89, B.94, B.95 and B.102

Over the period 1949-52 a series of Naval Fighter designs was studied, all using compound sweepback (sweep at different angles, usually increasing from tip to root). Interest in compound sweep at Brough arose from our commitment to design and build a vehicle for exploring in flight the wing planform proposed for the Handley Page Victor bomber. The wing shape was complex, with three different angles of sweep and with a cranked trailing edge. A scale model of this wing was to be attached to the modified fuselage of an Attacker jet fighter, and the aircraft was to be powered by a Nene engine. The HP.88, known at Brough as the YB.2, flew as VX 330 on 21 June 1951. Shortly afterwards it was handed over to Handley Page for the planned experimental programme. Unfortunately in late August, as a result of a pilot induced oscillation, it broke up in mid-air. The extensive pressure-plotting installation which had been fitted was never used.

The advantages of compound sweep did appeal to us but, for the application we had in mind, two different degrees of sweepback with a continuous trailing edge seemed to make sense. Thickness/chord ratio came out at 10 per cent at the root, 8 at the kink and 6 at the tip. This gave the desired aerodynamic effects, and also just sufficient depth at the position of the wing fold to allow conventional hinges and latches on the wing spars to be employed. On the F-4 Phantom, even with its 50 per cent greater folded width, the thinner wing necessitated the use of piano hinges with multiple latches.



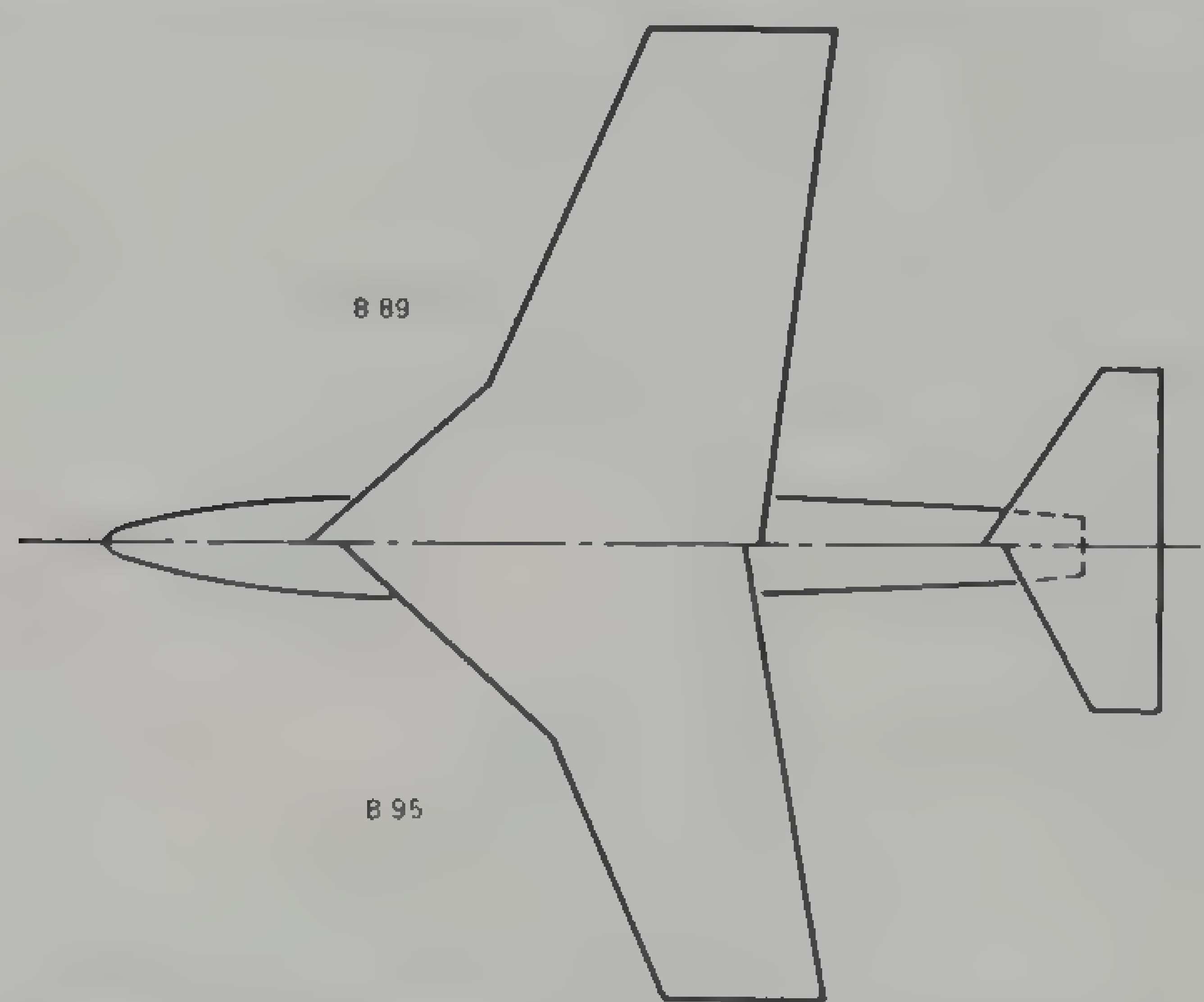
The B.89 — general arrangement.



The B.94 — general arrangement.

The first design under review was the B.82 of 1949. This was a quick exploratory exercise against a provisional specification N.14/49, and was powered by two Avon engines. It did not mature further for, shortly afterwards, tenders were invited against Specification N.114T for a naval all-weather fighter.

At this time the Royal Navy operated a wide range of aircraft carriers of varying capacity in terms of maximum deck weight and deck takeoff and landing



B.89 and B.95 — plan view comparison.

speeds. The problem was to produce a design capable of being operated by as many carriers as possible. Jet fighters operating from carriers were in the range 11,000-15,000 lb. The heaviest fighter, the piston-engined Sea Hornet, weighed a maximum of some 19,000 lb, and all had relatively modest approach speeds. The new all-weather fighter was going to be much heavier than these, and almost certainly faster on the approach. The specification called for a takeoff weight of not more than 28,000 lb (in-service, not initial project estimate) and an approach speed not exceeding 105 knots.

For the B.89 a single Armstrong Siddeley Sapphire engine was chosen. To meet the approach speed requirement a large wing of 700 sq ft was necessary,

and the span of 50 ft meant that a double fold had to be provided. The result of the study convinced the Royal Navy that the concept was going to be too heavy for the smaller carriers, and that, if operation was to be confined to the larger carriers, the approach speeds specified could almost certainly be relaxed. N.114T was therefore cancelled, and a rethink instituted.

Independently, we in the project office began our own line of investigation to see how a smaller and lighter aircraft could be offered. The first attempt explored a concept, then in vogue, of an undercarriageless fighter landing on a flexible deck. The resulting B.94 had the wing area reduced to 575 sq ft, with a span of 46 ft which would allow a single fold, but of course the exercise was largely academic.

The next step was to reduce both the avionics and offensive load in a well-judged manner to leave a reduced but acceptable operational capability. We took advantage of reduced weight to increase cruising altitude, and hence to reduce fuel load, and to add what we thought to be a reasonable 20 knots to the approach speed. The B.95 was the result, with a wing area of 425 sq ft, span of 40 ft and takeoff weight of some 20,000 lb.

Having been through this cycle, it became obvious to us that, with the reduction in the number of aircraft carriers then occurring, and with ships such as *Ark Royal*, *Eagle*, *Victorious* and even the smaller *Hermes*, major developments in catapult and arresting gear would allow much heavier aircraft to operate. A review written in 1952 said in connection with the B.95: 'Adaptation of a Royal Air Force design will result in a much higher weight than has been considered, but approach speeds and dimensions would be within the stated limits. If the higher weight is acceptable, there appears to be no reason why one should not be adapted to carrier operations and Naval Requirements fully satisfied.'

That is what eventually happened. Of the two competing aircraft to Specification F.4/48 the Royal Air Force selected the Javelin whilst the Royal Navy adapted the de Havilland 110 into the Sea Vixen.

During 1952, whilst these considerations were in progress, two more outline fighter designs were studied, the B.99 and the B.102. No trace of these now remains, but at least one was a follow-on to the B.97 rocket interceptor. Retaining the aerodynamic configuration already developed, a de Havilland Spectre rocket and a Bristol Siddeley Orpheus turbojet were the power units. This gave a much higher altitude intercept capability than with the B.89/B.95 concepts, at the expense of endurance but also with a greater dependence on control from the ship. Although a paper exercise, the studies were not without interest in investigating the effects of possible variables.

Towards the end of 1952 preliminary information was obtained about a possible Naval strike aircraft to succeed the Wyvern, and work on this began with a similar aerodynamic configuration. Thus began the B.103, which was to evolve into the NA.39 Buccaneer. The story of that evolution is told later.

Early Buccaneer Variant Proposals

Whilst the B.103 Buccaneer was being designed, built and tested, we sought to widen the market by proposing a number of developments: B.108, January

1958; B.109, January 1959; B.111, February 1960; B.112, March 1960; B.113, May 1960; B.116, June 1960, and B.117, December 1960.

B.108

In 1955 I was asked to visit Group Captain (later Air Chief Marshal Sir Neil) Wheeler, then DDOR.1 in the OR (Operational Requirements) branch of the Air Ministry. I was given preliminary information on a forthcoming OR for a supersonic low-level bomber for the Royal Air Force, later to become OR.339 and the TSR.2. Group Captain Wheeler — almost uniquely within the Royal Air Force — saw the possible advantages of making use of a variant of the Buccaneer. He suggested that Blackburn should put forward proposals, and this resulted in the formal submission in January 1958 of the B.108.

The B.108 — general arrangement.

Arguments put forward for the B.108 were that the supersonic dash capability specified would very rarely be used, and would incur very high cost. It was suggested that the cruising speed of the B.108, being some 0.1 M lower than that specified, was of little operational significance. Indeed, the speed available was if anything at the upper limit for human reactions to cope with the situation. Otherwise, performance requirements were completely or largely met, and all stipulated equipment could be fitted.

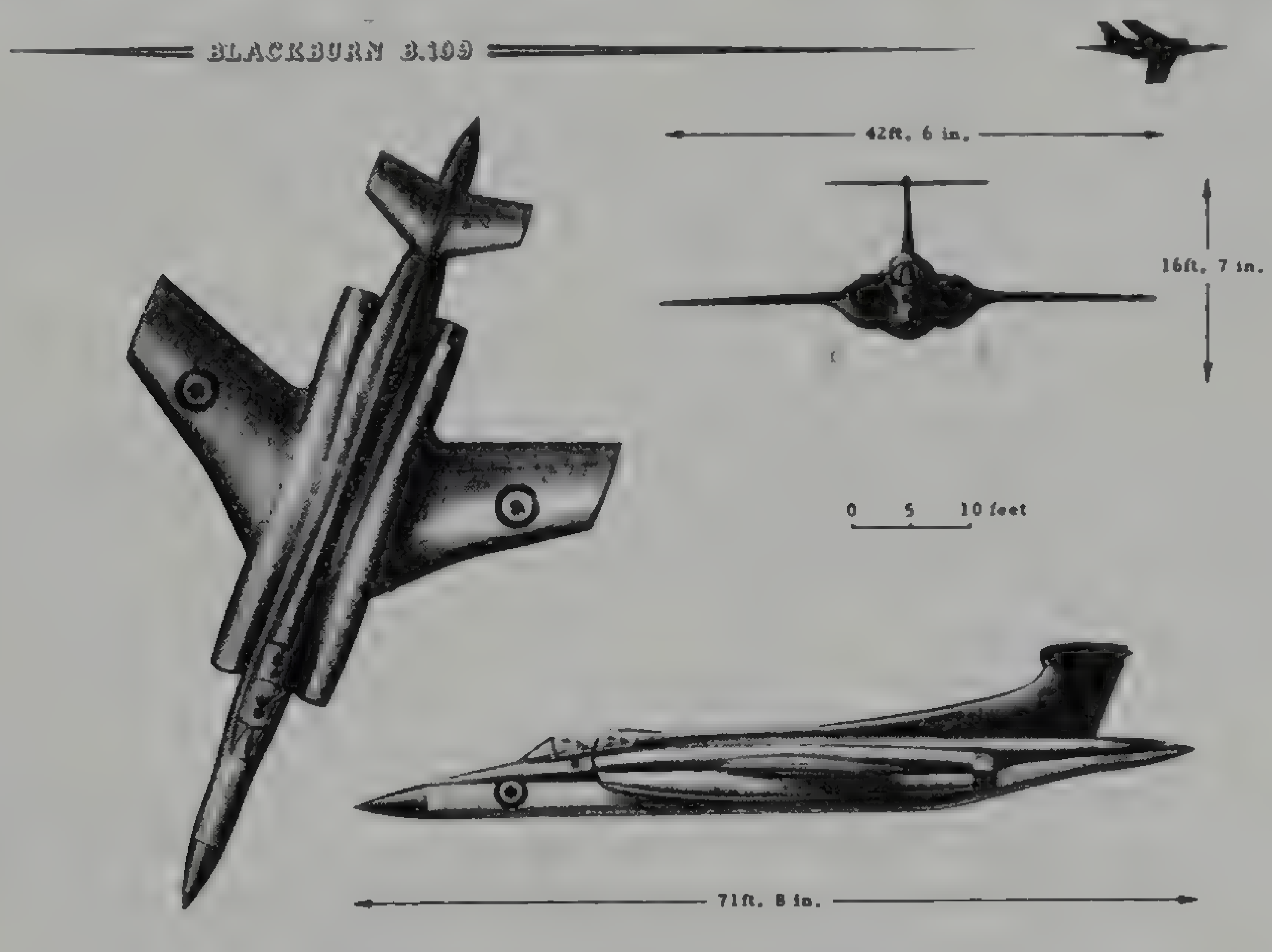
The length of the two-seat cockpit in the Buccaneer designed for the Royal Navy was dictated by two requirements: the ability of the navigator to assist in visual search, resulting in minimum pitch between the seats and the offsetting of each seat 3 in off the aircraft centreline, and the need for a restricted overall length for stowage in the carrier hangar and on the lift. This has been a source of annoyance ever since, when attempting to fit modern displays or a dual-control version.

For the B.108 both seats were on the centreline, and the cockpit was lengthened by 18 in to accommodate the radar and map displays. New radars, one sideways-looking for navigation and one forward-looking for terrain-

following and for ranging, were fitted in the new nose, together with an inertial navigation system. With the same internal fuel capacity as the naval version, wing drop tanks with their capacity increased by 60 per cent were proposed to attain the maximum ranges specified. The aircraft proposed had a basic weight only 2,000 lb heavier than its naval counterpart, and a takeoff weight 10,000 lb higher. Obviously, with the original 7,000 lb-thrust Gyron Junior engines it was underpowered, although on the face of it the B.108 met most of the basic performance requirements.

The attraction was thought to be the low cost relative to an all-new supersonic aircraft with, in theory, a decidedly earlier in-service date then quoted as 1963/1964. I added ‘in theory, because much of the avionic equipment proposed was in an early stage of development, and experience suggests that it would not have become available for service use until several years later than originally envisaged.

In retrospect, the B.108 proposal was one of the most unfortunate ever made. The fact that it was politically mishandled did not help, and the traditional reluctance of the Royal Air Force to adopt what was to them basically a naval



The B.109 — general arrangement.

aircraft can be readily understood. On top of this, to be persuaded to accept a device far removed from the flying machine they had in mind, and one which seemed to be grossly underpowered, led to a hardened attitude among many officers which lasted for many years. Had an initial proposal been made some four years later, based on the Spey-engined Mk 2, albeit as an interim type, it might have been more successful.

B.109

The B.109 was an unsolicited proposal made to the Canadian Armed Forces against their stated need for an interceptor and strike aircraft, and typifies the technical optimism prevalent at that time. A top speed of Mach 1.65 was

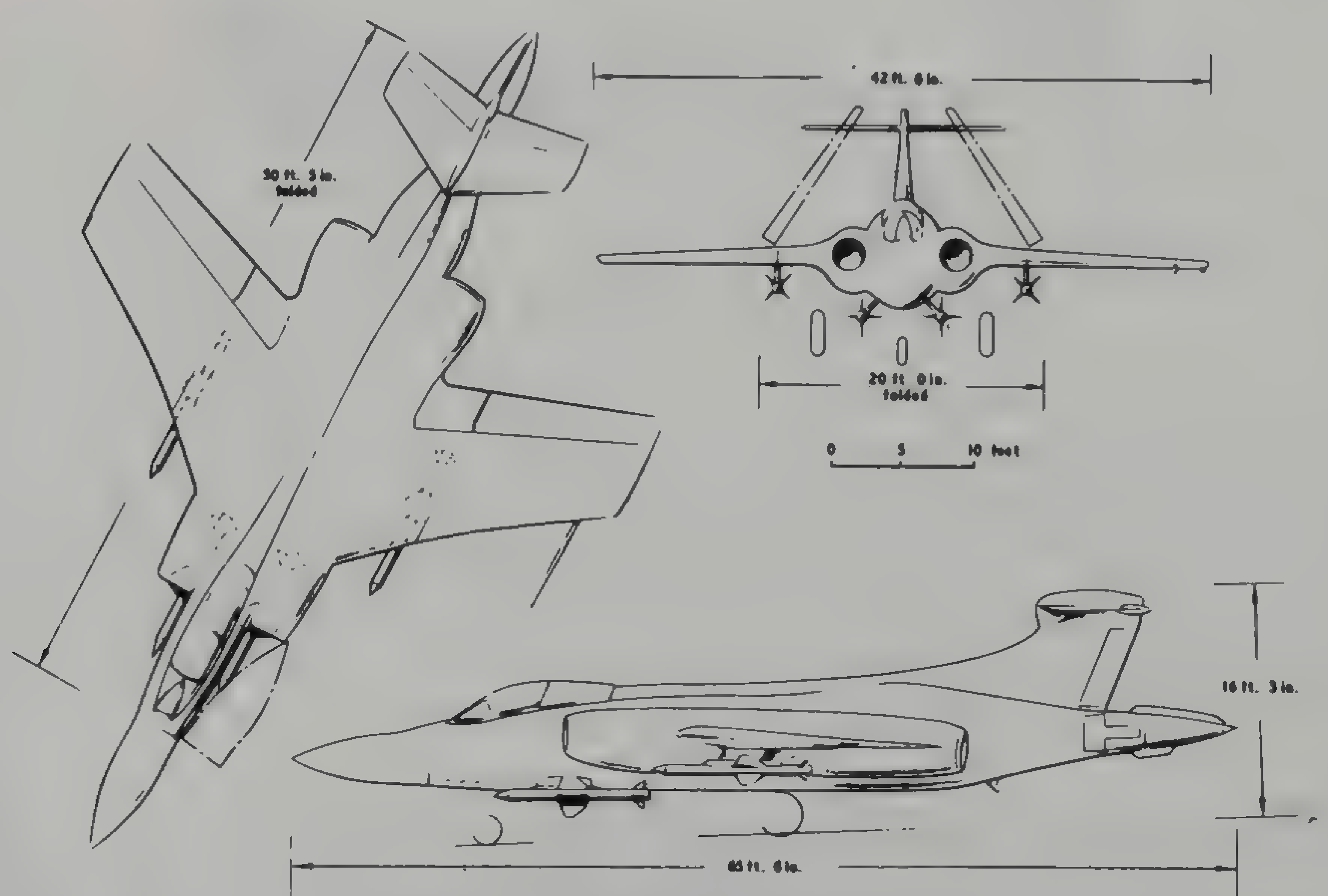
offered, to attain which the fuselage was lengthened at nose and tail by a total of 8 ft, a non-folding wing was substituted, with thickness reduced outboard of midspan, and the 7,000 lb Gyron Junior engines were replaced by reheated Rolls-Royce Avon RB.146 engines giving over 13,000 lb cold and 18,000 lb reheated. Attack sensors were to be totally different from those in the NA.39, but much of the basic equipment could be retained.

The NA.39 was ordered in 1955 and scheduled for entry into service in 1961. The B.109 brochure of 1959 suggested an in-service date of 1963 to be practicable. It would have been difficult to be responsible for changes of the magnitude proposed in any timescale, on top of the full programme already in hand, let alone in the truncated timescale suggested. A team visited Canada to pursue the proposal but were unsuccessful in arousing interest, although it was described recently as the best-looking Buccaneer proposal ever drawn.

B.111, B.112, B.117, B.113 and B.116

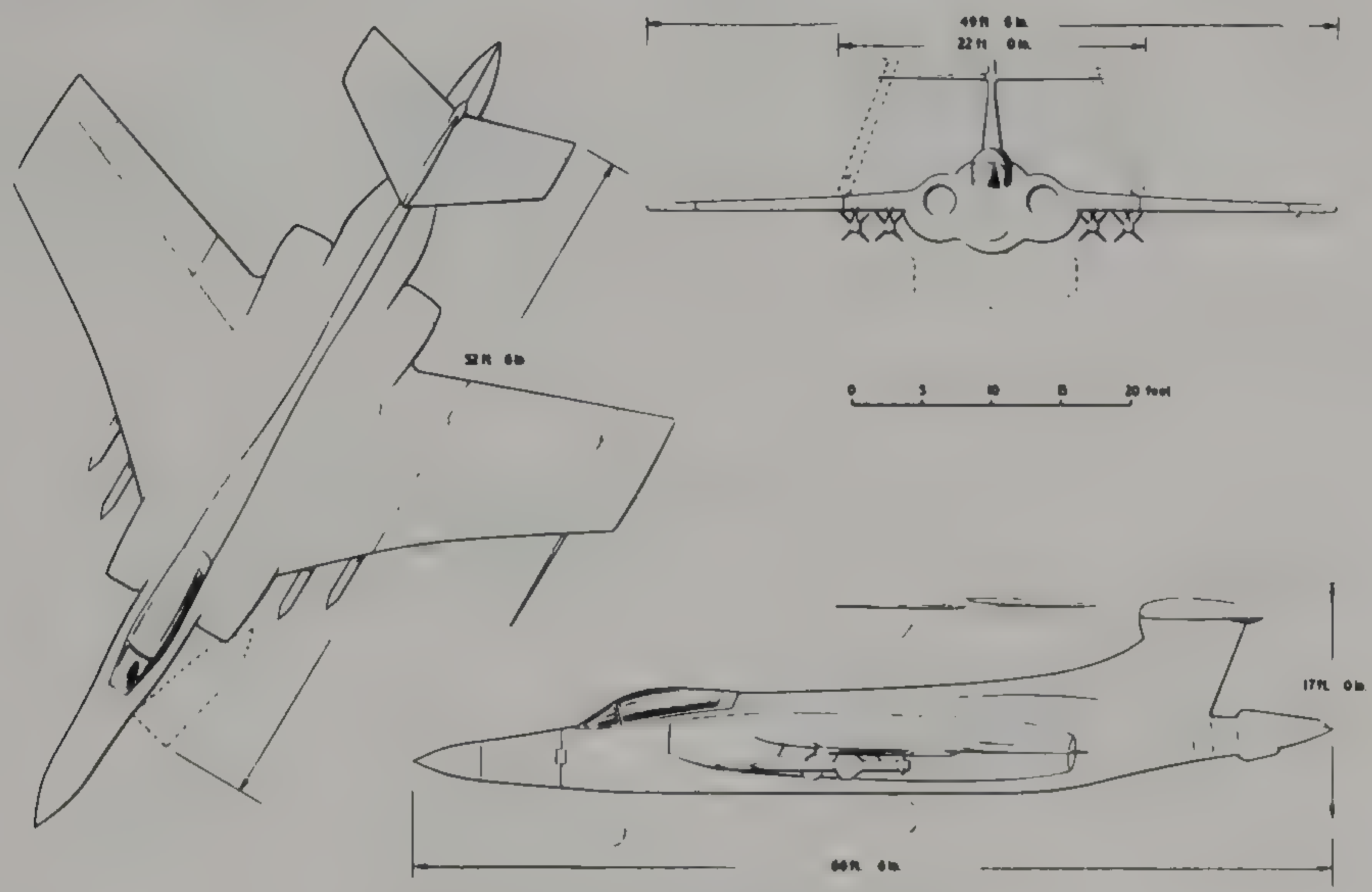
It was at this stage that, with the scaling-down of the Rolls-Royce RB.141 Medway to the RB.163 Spey, as a result of British European Airways' revised specification for their DH.121 (later Trident) trijet airliner, that details of a military variant of the Spey became available. Both unreheated and reheated versions of the Spey were studied for possible application to B.103 variants. Later, of course, an unreheated Spey was to be incorporated with great success into the Buccaneer Mk 2. The engine was quoted with a thrust of 11,000 lb unreheated and 18,000 lb with reheat.

The B.111 proposal of 1960 was offered to the Royal Air Force with a slightly modified non-folding wing, an inertial platform, the radar and displays modified to encompass the roles envisaged, together with the new engine installation. The wisdom of including reheat in this proposal must be open to some doubt. Basic weight was increased by some 5,000 lb, relative to the then naval aircraft, with the takeoff weight up to 13,000 lb higher.



The B.112 — general arrangement.

The B.112 was simultaneously offered to the Royal Navy as a combat air patrol fighter. Apart from retaining the folding wing, the proposal was very similar to the B.111. The aircraft remained suitable for the strike role, but in the fighter role a removable fuel tank could replace the bomb door and bay. For deck operation maximum takeoff weight was restricted to 8-10,000 lb less than that possible from airfields, but nevertheless a creditable range and endurance was available, with a predicted top speed in the region of Mach 1.5.



The B.117 — general arrangement.

The B.117, which followed later in 1960, had a bigger wing and tailplane to improve high-altitude performance and manoeuvrability, at a 1,500 lb penalty in basic weight, and still subject to the same shipboard takeoff weight limitations. Wing area was increased from 508 to 700 sq ft, with the resulting increased span of 50 ft necessitating a second fold, accomplished by downwards-folding of the wingtips.

Each of these three variants was offered for in-service 1964/1965, a date subsequently attained by the less-ambitious Buccaneer Mk 2.

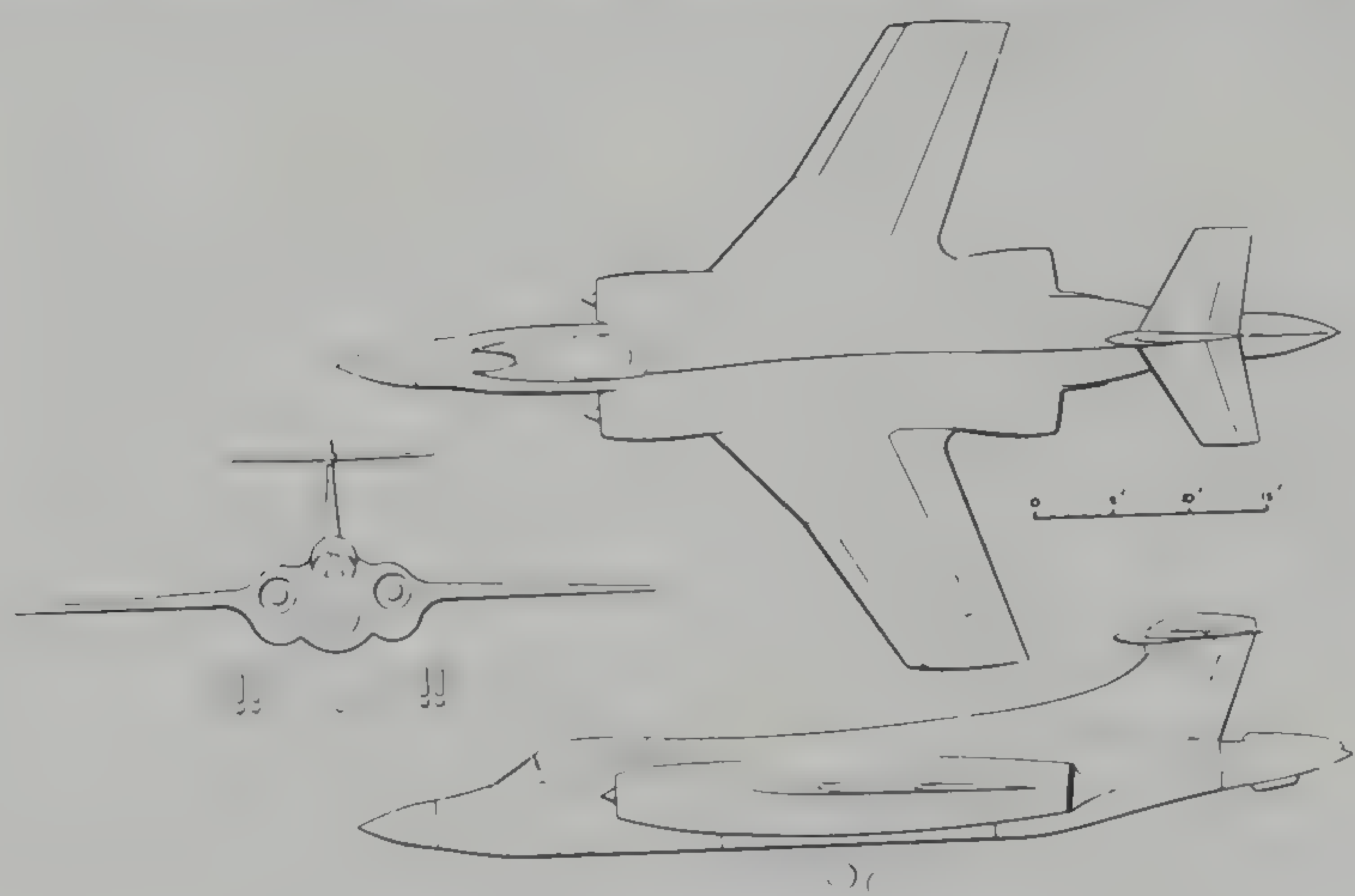
The B.113 was virtually identical to the B.111 and constituted an offer to the Royal Australian Air Force for a strike and all-weather intercepter aircraft. In 1959 serious attempts had been made to sell the NA.39 in its original configuration to the West German Navy. At the time in late 1960 when replacement of the Gyron Junior by the unreheated version of the Spey was in the process of being agreed for Royal Navy application, the opportunity was taken to follow the previous submission with a non-folding-wing version of the Spey-engined aircraft, and this was designated the B.116.

Other Variants

This completes the story of NA.39 derivative proposals forming submission to potential customers during the evolution and entry into service in 1961 of the Buccaneer S Mk 1. During this period I was preoccupied with the flight development programme, but retained a loose connection with the Future Project

Office and in 1961 became full-time responsible for the Buccaneer Mk 2 programme. However, in April 1962 I was appointed Assistant Chief Designer, with the Future Project Office now headed by Rod Melling within my jurisdiction. During this changeover period, investigations of minor Buccaneer developments were undertaken, as shown on the chart, which included the B.124, 126, 127 and 128. The B.129, later the P.140, was a fighter version of the Buccaneer with a Mach 1.8-2.0 capability. A landbased version with a low LCN undercarriage was devised, and this landing gear was subsequently used in several later proposals.

The subsequent story of the B.129 seems to be worth telling. With a wing thickness/chord ratio of 6 per cent throughout, redesign of the tailplane and



The B.129/P.140 — general arrangement.

attachments to cater for the supersonic loadings and with reheated Spey engines, it was revitalized in 1964 as the P.140 for carrier-borne fighter application. The main problem in our mind was the unavailability in the United Kingdom of a suitable modern AI radar; however, we submitted a proposal to the Ministry of Defence. The reply which we received was a ruling, I believe by the organization under Sir William Cook, that there was 'no operational requirement'. Several months later the order was announced for the Spey-engined Phantom, which was to fulfil this very role. It did have the advantage of the complex Westinghouse radar, which probably could not have been made available for a British project. (Little did we know at that time what our involvement in this Phantom project would be.)

To complete the pre-1963 era of Buccaneer proposals, P.132 and 133 looked at rocket-assisted takeoff possibilities for the S.1 and S.2 respectively, whilst P.134 started the work on an improved weapon system and associated airframe changes, later to be known unofficially as the Mk 2*. The P.136 constituted the initial proposals to the South African Air Force which eventually, with some modifications, resulted in the Buccaneer Mk 50.

Possible Buccaneer Successors

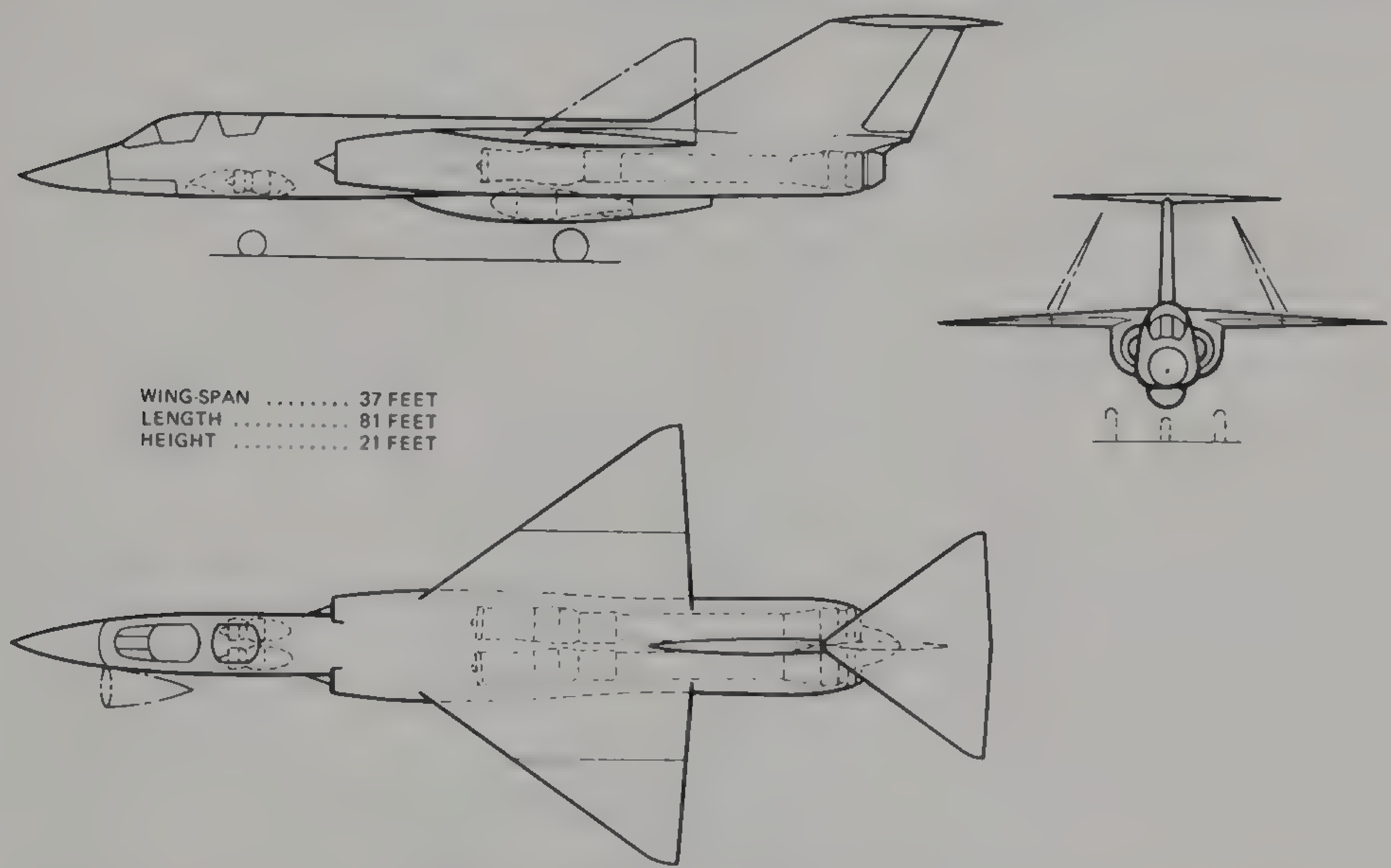
In 1961 nobody had the slightest idea that the Buccaneer was to have an operational life well into the 1990s, nor appreciated the unaffordable cost of

developing new advanced projects at the rate which had previously applied. Any future project office would be lax if it did not investigate possible exploitations of the constantly developing technology and state of the art. It is how much resource to put into any specific project investigation which is a matter of judgement. This can range from, say, six men for six months to a sizeable team with technical and wind-tunnel and rig back-up costing possibly several million pounds.

B.123

The B.123 investigation was definitely in the former category. The concept was to have a cruising speed of 0.95M, a radius of action on a high-low mission of over 1,000 miles, a top speed of at least 2.0M and an approach speed of between 80 and 100 knots. Certainly ambitious targets.

A 5 per cent thick, 55°-delta wing was considered to be a good compromise,



The B.123 — general arrangement.

but a tailplane appeared to be essential for damping in the high-speed low-level cruise, and for trim and control for landing.

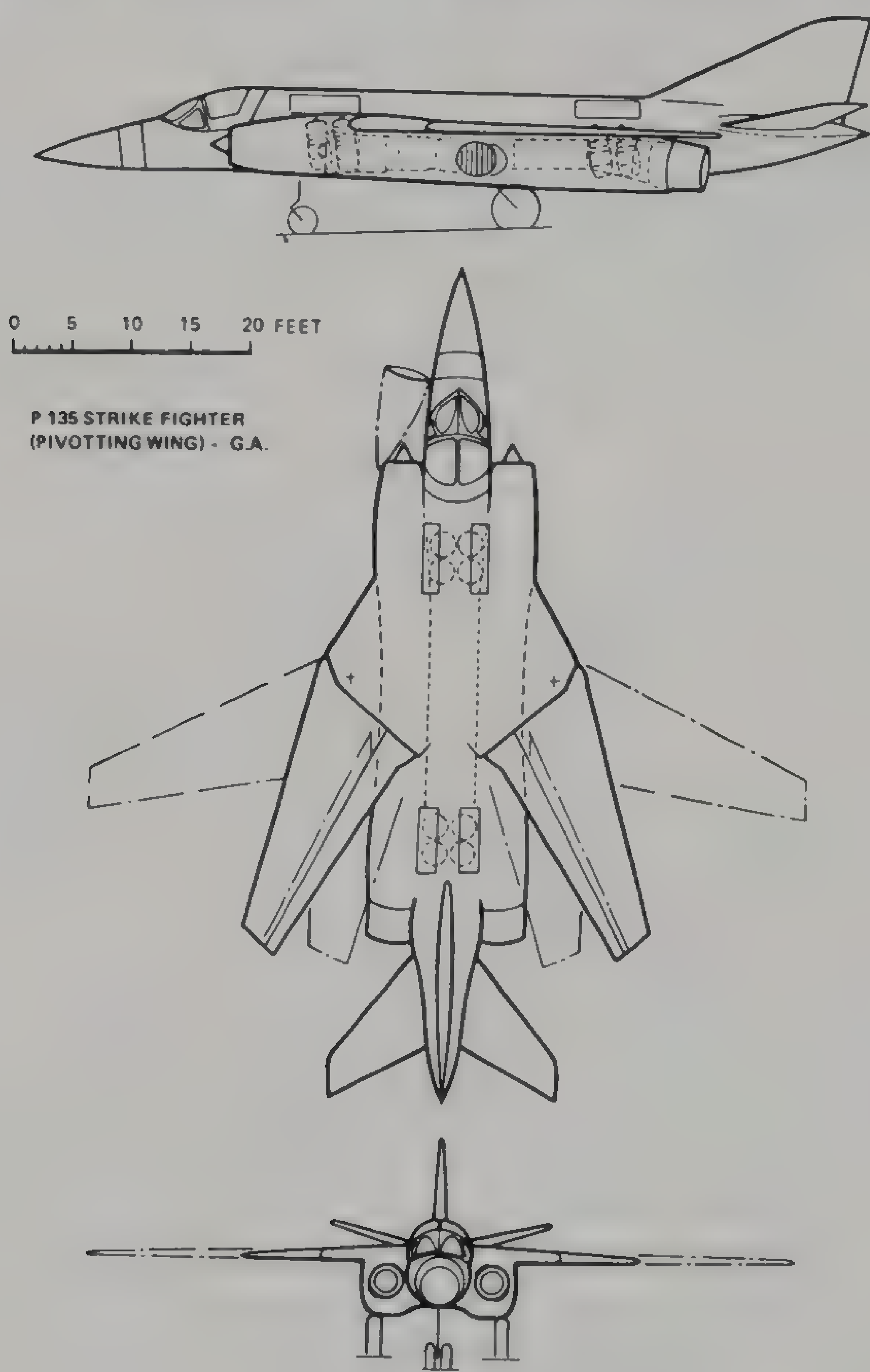
Two reheated Spey engines were chosen for propulsion, and a complex combination of devices proposed to obtain the very low landing speed. A proportion of the unreheated thrust of the main engines would be deflected downwards aft of the centre of gravity, to be balanced by 4,000 lb-thrust lift engines mounted forward. Leading- and trailing-edge flaps were all to have boundary-layer control using air bled from the engine compressors. Wing area was 550 sq ft, basic weight 35,000 lb, and takeoff weight 56,000-60,000 lb, with offensive stores carried externally in minimum-drag installations. The brochure states that an anticipated in-service date was the early 1970s.

P.135

Following this 1961 exercise, a further investigation began in 1962 to study a possible supersonic Buccaneer successor. Retaining the reheated Speys, the

P.135 considered the use of variable wing sweepback as part of the solution, investigating both translating and pivoting mechanisms.

Sweep of the 10 per cent thick wing varied from 25° to 63°, with associated spans of 30 ft and 60 ft, respectively. Fulfilling a mission very similar to that specified for the B.123, it was likewise estimated to have a basic weight of around 35,000 lb and takeoff weight of 56,000-60,000 lb, and appeared to be a



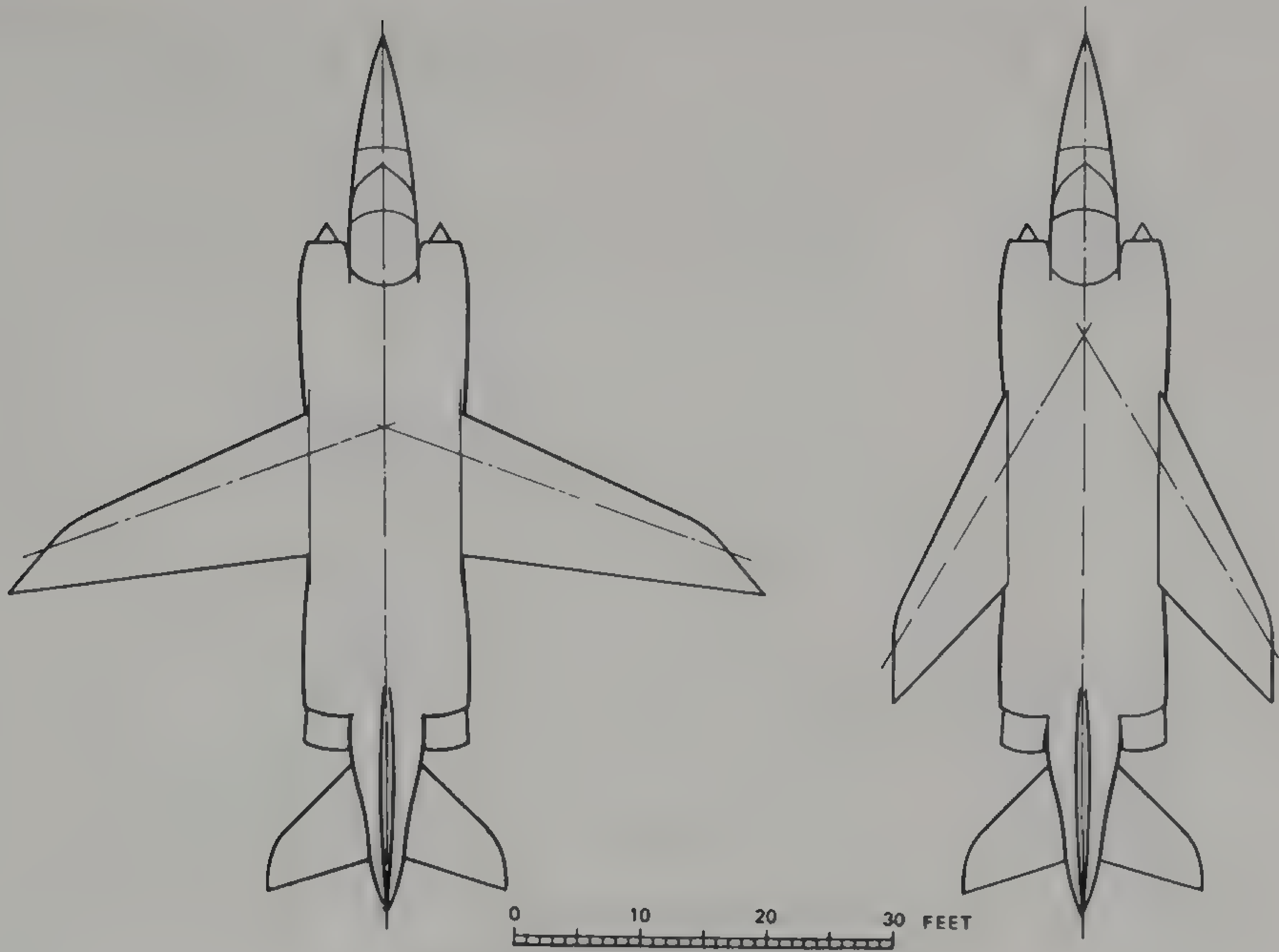
The P.135 — Pivoting Wing.

far more practicable proposition than the B.123. It was described in some quarters as merely an attempt to produce a British replica of the F-111, which at that time was in early development in the United States.

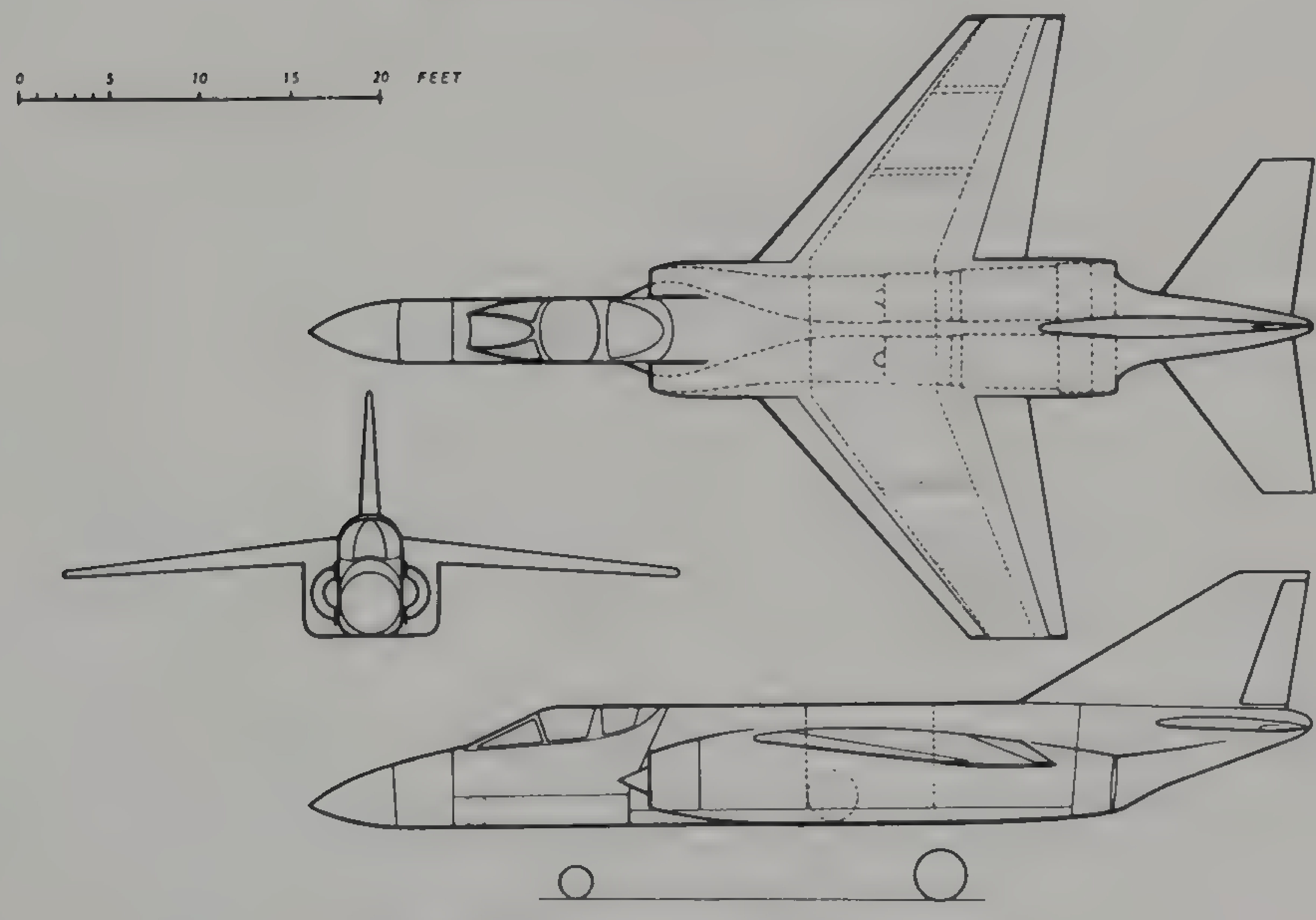
The reader may be confused by the transition from the B prefix to P. With the total integration of Blackburn, Avro, Folland and de Havilland into the Hawker Siddeley organization, each site adopted the P prefix, whilst retaining their previous numerical sequence. The only overlap between project numbers was for those originating from Brough and Hatfield, where the sharp demarkation between civil and military projects avoided any difficulty.

P.141

In 1965, as the brainchild of Rod Melling, came the last of our attack projects, the P.141. This was offered as an alternative concept to the MRCA (later



The P.135 — Translating Wing.



The P.141 — general arrangement.

Tornado). The proposal was to avoid the size and complexity incurred by having an airframe with the capability of fulfilling a number of roles by a modular approach, where role-related major components could be attached, on the assembly line, to a common core, thereby producing a smaller and cheaper product.

Powered by two Bristol Siddeley/SNECMA M45G turbofans of 7,460 lb dry and 13,000 lb with reheat, the P.141 had a wing area of 400 sq ft, span of 35 ft and length of 56 ft. Basic weight was 23,000 lb, with a normal takeoff weight of 38,000 lb. Maximum speed was about Mach 2, and radius of action up to 1,000 miles. A good short-field performance was also a feature of the design.

The lessons to be learned from these studies were that, at considerable expense, with the technological advances which had occurred, a Buccaneer successor with supersonic capability but still compatible with the larger carriers was feasible. However, for the strike role, the supersonic capability was of little use, the fighter application was well looked after by other projects in hand, and the established international programme leading to the Tornado rendered consideration of other projects in this class redundant.

Although this section is essentially concerned with Brough future projects, two topics were ongoing after my move to Warton. Accordingly, to maintain continuity, the activities at both sites are integrated in the following.

Remotely Piloted Vehicles and Intelligent Weapons

The term RPV (Remotely Piloted Vehicle) is used to describe an unmanned vehicle launched either from the ground or from an aircraft and subsequently controlled from the launching site or an air vehicle. It can be either recoverable or non-recoverable. The advancement of technology for such vehicles has progressed to allow wider applications where, for instance, the designated mission can be completed after launch without any further external control.

Reconnaissance, where the payload is a small proportion of the total weight and the threat from defences is high, is one area where the RPV can be an attractive solution. The Canadair CL-89 and CL-289 are widely used for this application. This generation has a limited range, suitable only for battlefield surveillance, a mission programme preset into the vehicle before launch, and film recording of camera and infrared linescan which in the case of the CL-89 has to be read after recovery of the vehicle by parachute. Real-time data transmission is a feature of the CL-289.

The drive with new technology is for a vehicle with a secure data-link, both for command and for real-time transmission of the reconnaissance data obtained. Increased radius of action must also be an aim, but countering this is the problem of the data-link. In the meantime, longer-range missions must continue to be accomplished by manned aircraft, albeit with increasingly sophisticated equipment.

Defence suppression, either by jamming transmissions or by direct attack on radiating stations, is another obvious area with either an air-launched or ground-launched vehicle. In the category of anti-radiation missiles the British Alarm and the American HARM are typical of what can be done. Both are sophisticated and expensive, but if they are successful the pay-off could be high.

At the other end of the scale, the application of model-aircraft technology can produce relatively cheap but effective vehicles for some recoverable roles over short ranges. Israel has well shown what can be achieved in this class.

There is a wide choice of vehicle size and weight within these categories, from a few hundred pounds up to 4,000 lb in weight. Operational and technological conflicts have delayed firm decisions on the way forward, particularly for the reconnaissance role, and it is very difficult to make predictions for the future. Even with a real-time data-link established for battlefield operations, the processing and distribution of the data obtained is subject not only to technical controversy but also to organizational problems such as how to distribute,

interpret and act upon the data gathered, which can involve inter-service problems. NIAG (NATO Industrial Advisory Group) Sub Group 2 met many times in Brussels to propose battlefield reconnaissance systems, but repeatedly foundered on such points.

NIAG drew together experienced industrialists to address themselves to specific topics, and to pass on their conclusions to the NATO authorities (the National Armament Directors). However, NATO in itself is not a purchasing authority, so there is no question of specifications and invitations to tender followed by orders arising. Hence, as a member of NIAG one felt that one had no teeth and, moreover, one could be wary of a fellow member pursuing a nationalistic or commercial line. To everyone's credit this did not appear to be so, and a useful pooling of knowledge and meaningful personal contacts, which might otherwise not have been made, must have justified the time and money expended by the companies involved. Realisation of specific projects remains with the governments and industries of each individual NATO nation — on either a purely national or, as is more common these days, international basis — but they benefit from the NATO-based discussions which are held.

The attack of point targets which are readily identified, and hence probably heavily defended, is another area where stand-off missiles should find a ready application. Airfields, bridges and strategic buildings are of course fixed points, but armoured columns on the move present a different set of problems. Whilst ground launching of stand-off missiles is one solution, greater flexibility comes from air launching from an aircraft, which is not only more mobile but is also capable of fulfilling another role.

Currently such targets are attacked with 'iron bombs', which can be converted into precision laser guided 'smart bombs', or by a dispenser releasing a shower of bomblets. Sensor developments now allow a limited target intelligence to be installed in each bomblet. This increases lethality, but still requires the aircraft to overfly or closely approach the target, with high attendant risk.

At a 50 per cent increase in weapon weight, which should still allow its carriage from most aircraft stores stations, a self-propelled missile with a very good stand-off range is feasible, and would in most cases ensure launch aircraft immunity. The advent of relatively cheap strapdown inertial navigation and adequate data-processing capacity means that, provided sensors can identify whatever target is designated, the whole concept is viable. Recent experiments show that such sensor performance can now be provided, and NATO partners are working on an LRSOM (long-range stand-off missile) and MSOW (modular stand-off weapon).

The type of missile suggested would cost up to 15 times as much as the current dispenser weapon and 25-30 times as much as an 'iron bomb'. However, crude analysis suggests that the kill rate could be improved at least fivefold, and, if we take into consideration the effect of the reduction in loss-rate of the launch aircraft, overall cost per kill is improved something like tenfold. The problem then is the perennial one of development and procurement costed on a peacetime or wartime basis. Can we afford to procure this sort of stand-off missile or, alternatively, can we afford not to? It is certainly dangerous to base the decision on an assumed scenario, because, invariably, real life throws up a totally different situation within the time of a project cycle. To illustrate this, it is unbelievable that the advocates of STOVL prior to 1960 foresaw the Falklands situation,

where, without the Harrier, things would probably have turned out very differently.

Air-to-air combat is also likely to be influenced by sensor and data-processing developments, but to what extent this may affect the desirable characteristics of the aircraft involved is much more uncertain. For close-in combat with guns, or with many current short-range missiles, the tactics were roughly the same but with different ranges. In either case it was highly desirable to position into the rear hemisphere of the target with a firing boundary limited to what would normally be within the visual acquisition and identification range. This therefore leads to the classic dogfight type of situation, requiring high manoeuvrability down to what may be surprisingly low speeds.

The current MRAAMs (medium-range air-to-air missiles) such as Sparrow and Sky Flash home on to a target illuminated by the launch aircraft's radar. Maximum launch range is well beyond visual acquisition range, so some degree of uncertainty will always exist. A1M-120A AMRAAM, now in service, homes itself on to the designated target, but any launch aircraft lacking this weapon is committed to every specific attack; any need for it to take evasive action could abort that particular attack. At present MRAAM-carrying aircraft also include SRAAMs (short-range air-to-air missiles) in their inventory, so a dogfight level of manoeuvrability is highly desirable.

Next-generation SRAAMs have a detection capability which contains a significant foward sector of the target, and one which is beyond the visual acquisition boundary. Hence the rules of combat and their associated performance and sensor requirements may be entirely different — or will they? He would be a brave man who would dispense with the traditional, but ever-increasing, level of fighter manoeuvrability.

Next-generation MRAAMs, such as the US Navy Advanced AAM, could well have up to double the launch range of current types; but will anyone have the courage to launch at what may well be a largely unidentified target so far away? On the other hand, the missile's autonomous range after launch will be similar to the maximum launch range of current MRAAMs, enabling the launch aircraft at these ranges to 'fire and forget' and immediately to address another target or take any evasive action which may have become necessary without aborting the launch previously made. The increased cost of these missiles will be offset by the increased number of kills per fighter sortie and the reduced losses in the fighter force due to its increased freedom to manoeuvre if itself attacked. Once again, however, this brings in the quandary between peacetime and wartime costing.

There may well also be arguments regarding the performance and manoeuvrability to be built into an MRAAM-launching aircraft. Two conclusions have led us to go for the maximum attainable: the greater its total energy at launch, the more effective is the missile; and with sufficient manoeuvrability and acceleration the aircraft can avoid an attacking missile until the latter runs out of energy — provided, of course, that the missile is detected in time.

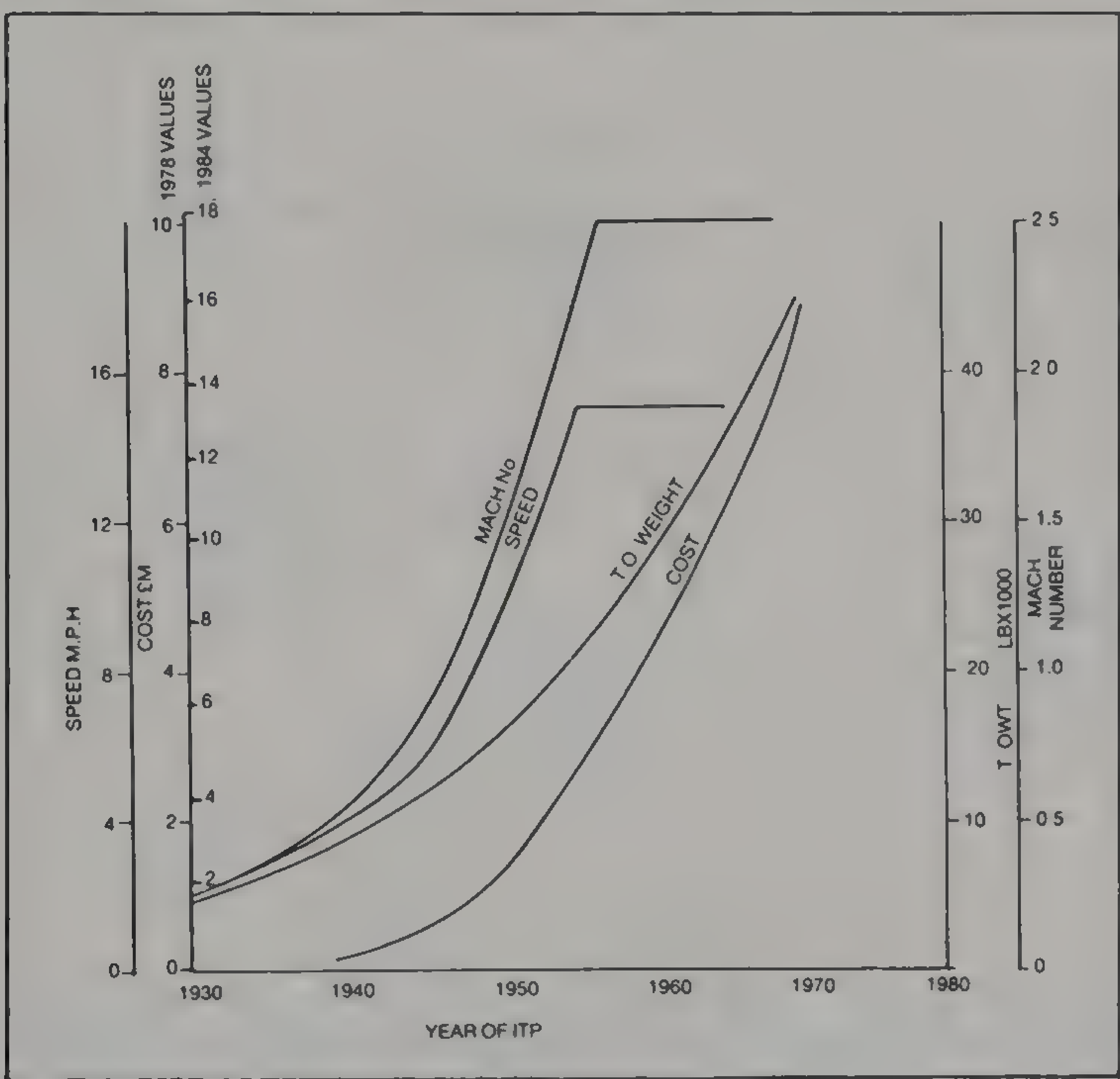
What seems to be clear is that there is such a wide range of choice of new weapons, many of which can have some interaction on the necessary features of combat aircraft, that liaison between the weapon and aircraft designers must be closer and more continuous than has been the case in the past. The problem is made more difficult as project cycles of the two elements will rarely coincide,

and continuous evolution which must take place must incur a degree of flexibility from the other side.

The Lightweight Fighter

The term lightweight fighter can be traced back as far as the late 1920s, but the species became important in the 1950s in the F-5 in the USA and the Gnat in the United Kingdom. It is of note that neither found itself in the fighter role in the inventory of its country of origin. Both were used in dual-control variants for advanced training, and both had some export success in the fighter/ground-attack role.

The progressive increase in weight, complexity and cost of fighters designed to the specifications of the major powers has for many years been leading to a situation where, even for the prime nations, the numbers affordable are embar-



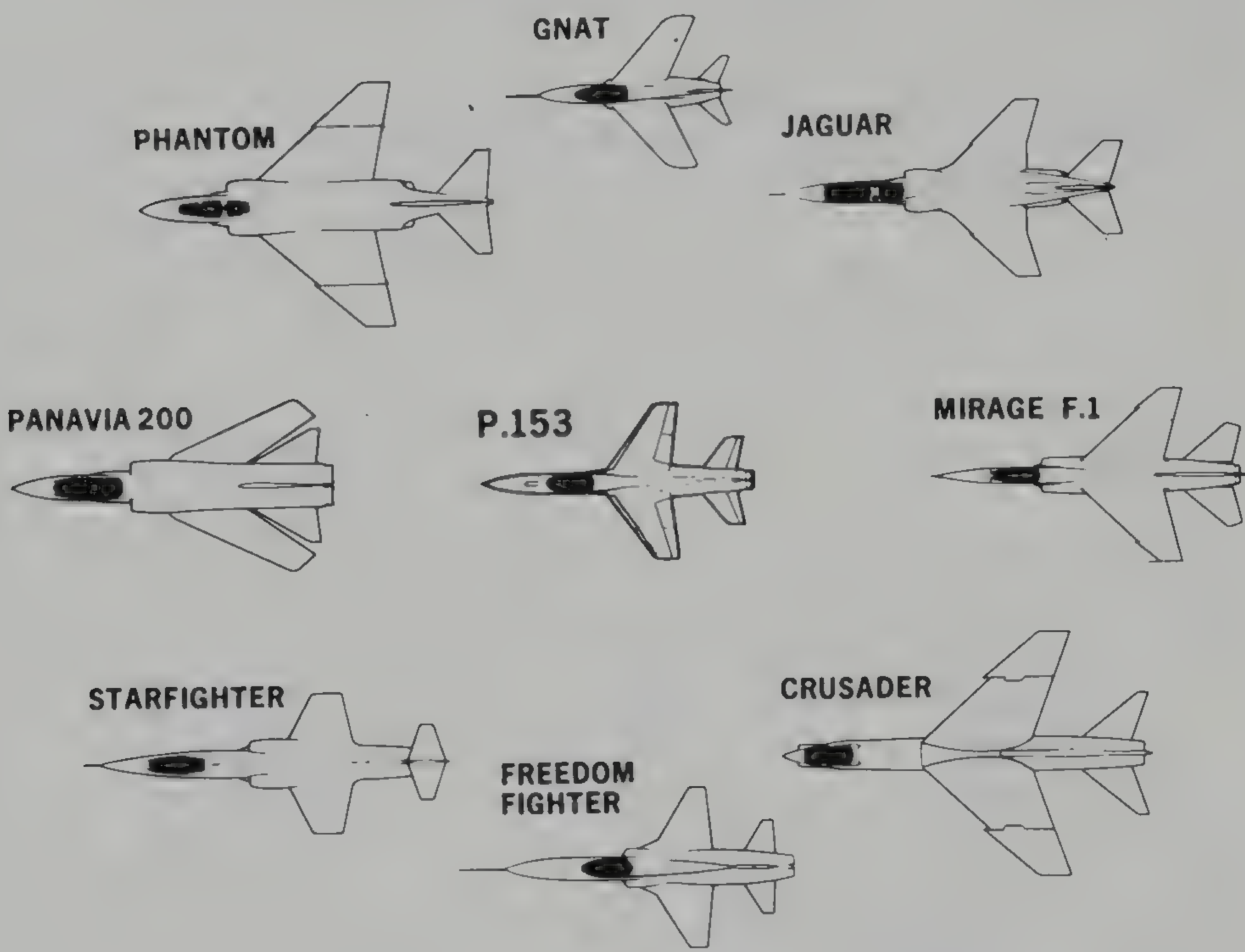
Fighter growth.

rassingly small, and the more torturous path of international collaboration becomes a necessity. Additionally, a sizeable export to smaller nations can be lost due to their inability not only to afford the aircraft but also to maintain and operate it.

The growth of fighter weight and combat performance are illustrated, together with the plan views of existing fighter types plus an indication of where instinct tells us a modern lightweight fighter should be.

The lightweight fighter is an area in which I was continuously involved from 1970 up to my retirement in 1984, at both Brough and Warton. Throughout this period, no favour was found in the concept within the Royal Air Force, who constantly wanted STOVL or an advanced twin-engined fighter now emerging as the collaborative EFA, or even in some quarters a combination of both.

There has therefore been no Operational Requirement over this period, and possible solutions have been left largely to the instinct and judgement of the designer. Towards the end of the period several nations, each with either an established although limited industry, or with an embryo one with a political will to develop it, saw the light combat aircraft as a solution not only to their re-equipping programme but also as an ideal vehicle for progressing the advancement of their own industry. It was therefore not unnatural for them to discuss



P.153 size comparison.

the possibility of a collaborative project, or, failing that, a technical assistance arrangement with those elements of British Aerospace which had been occupied with the appropriate studies. It was in this connection that I found myself over a number of years shuttling to and from India and Sweden, although there were also a number of other possibilities under discussion.

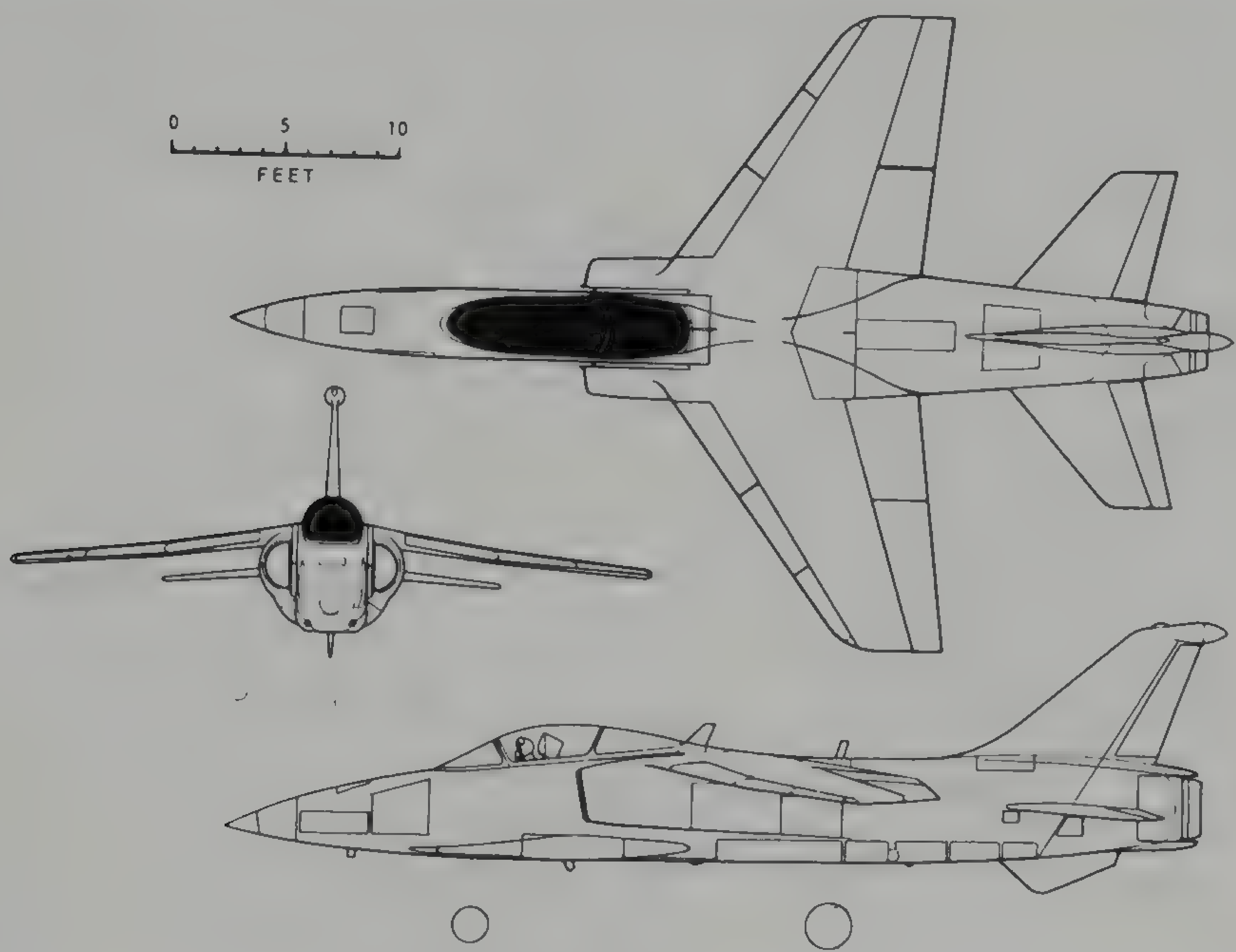
On one occasion, on the point of departure to India I received an urgent summons to Sweden. On completion of a two-week stay in the tropical heat of India we arrived back in the United Kingdom on a Saturday only for two of us to find ourselves on the Monday in the depths of a Scandinavian winter. Never can the adaptive powers of the human body have been more thoroughly tested, in spite of an appropriate change of outerwear!

The overall concept and possible markets for a modern lightweight fighter were discussed by Roy Braybrook in an article in *Air International* of June 1981 where he suggested a gross weight in the region of 20,000 lb, a thrust/weight ratio of about 1.0 and a combat wing loading of some 60 lb/sq ft. There can be little disagreement with these proposed parameters, although from the options

available a thrust/weight ratio some 10 per cent less than the value proposed seems to be the best that can be achieved. His suggestion that the use of composite structural materials be avoided may have been right at the time, but is certainly not the case today.

In one sense the designer has been faced with a paradox in reviewing lightweight fighter possibilities. Advances in structural materials and avionics have been proceeding apace. The more one took advantage of these, the more attractive was the capability, but the cost and risk factors involved were in opposition to some of the original aims of the concept.

At Brough the first definitive light-fighter design was the P.153 of 1970. This would have had a useful ground-attack capability, but it was primarily a highly



P.153 — general arrangement.

potent interceptor fighter for operations in the battlefield zone where most of the combats would be at low or (rarely) medium level.

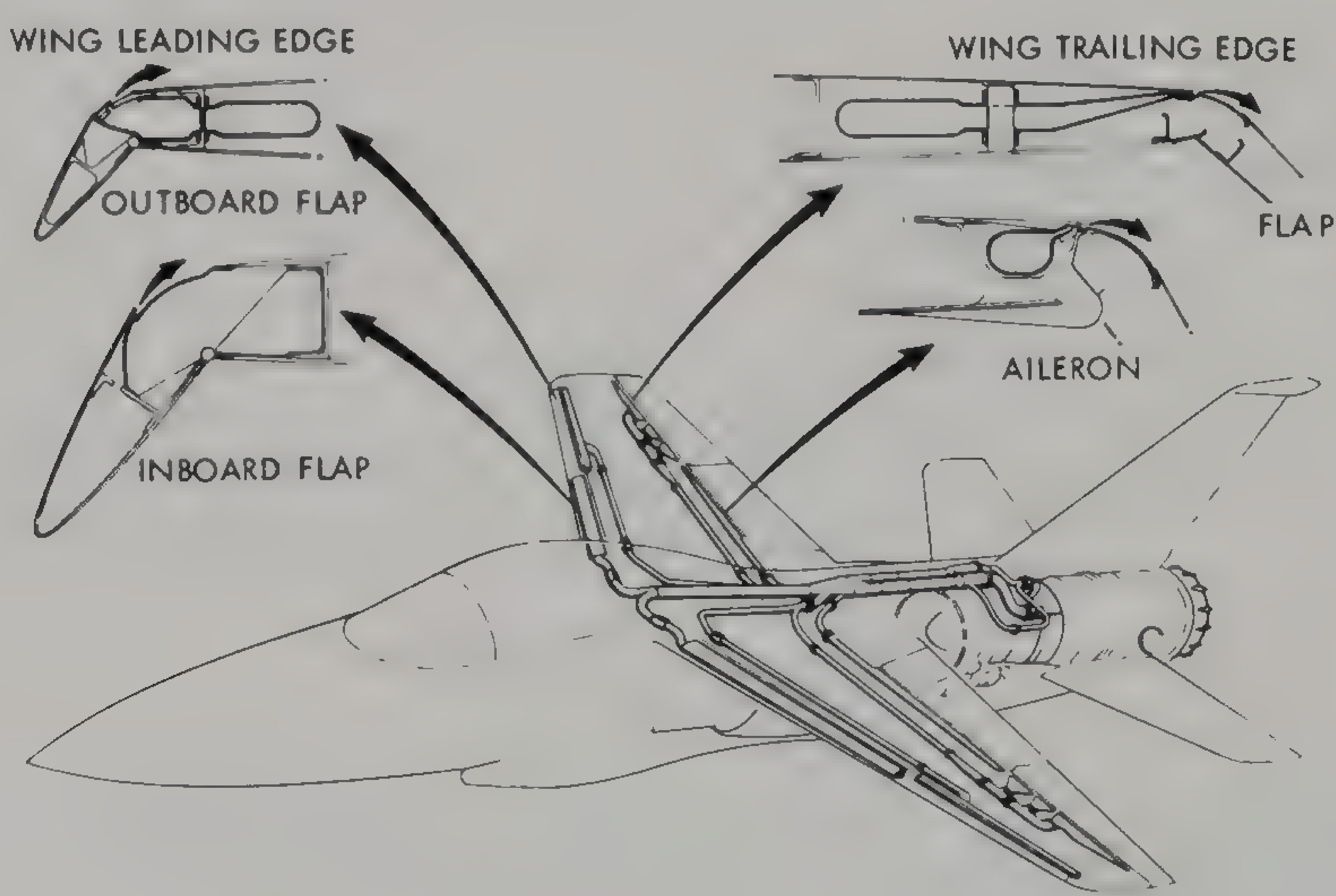
Extensive computer modelling and simulator experiments were undertaken, with particular reference to performance and manoeuvre, sensor requirements and fuel capacity associated with likely intercept missions and combats deduced from the computer/simulator results. With the battlefield environment very much in mind, a good STOL performance, defined as takeoff and landing runs not exceeding 1,200 ft, was regarded as of prime importance. At the time of the P.153 design certain features now considered to be basic in a lightweight fighter were excluded, among them composite structural materials, fly-by-wire/active controls and ultra-high manoeuvrability (5g was taken as the maximum usable for sustained manoeuvring).

To minimize weight and cost a new approach was made in respect of the avionics package. Our studies showed that, provided the fighter could be positioned within 15-20 miles of the target — which could be by direction from

ground control or early-warning aircraft, or happen naturally in a battlefield environment — the state of the art in infrared sensing and data processing would provide adequate tracking, and in some cases be superior to a radar. On the assumption that a laser ranger would be included for ground attack, it was felt that this could be slaved to the infrared tracker to give the ranging facility for air-to-air attacks. This could save 25-30 per cent of the installed weight of the avionics package, and save even more on cost. The proposal was regarded in some quarters as heresy, and did require development of specific equipments for which no programme was then envisaged. We persisted with the idea for several years but eventually abandoned it, particularly as suitable radars began to become available.

The initial P.153 design attained the STOL performance by applying boundary-layer control to both leading- and trailing-edge flaps, where, with later development, we predicted a 50 per cent greater maximum lift coefficient than had been attained on the Buccaneer. To match takeoff performance a thrust reverser was essential for landing, and it was regarded as advantageous if this could be used in flight, particularly on the approach to increase engine revolutions and hence blowing pressure.

The smallest and lightest aircraft would result from the use of the RB.199



P.153 Boundary layer control system.

engine, and this was regarded as the datum, although earlier and more developed engines such as the Spey and F100 were considered as alternatives. Although one was always looking for the next proposed stage of development of the RB.199 to obtain the desired level of thrust, the risk seemed well worth taking. The alternative engines mentioned gave roughly the same performance in an aircraft that was 35 per cent heavier, correspondingly larger and more expensive. Hence since 1975, lightweight fighter designs have been based on use of the RB.199 with, in later years, the General Electric F404 as a very credible alternative.

The air bleed for boundary-layer control proved to have complications. Simply using fan air gave adequate pressures for takeoff, but not so at the

reduced revolutions for landing, for which the additional use of some high-pressure compressor air mixed via an injector was proposed.

As time went by, the use of leading- and trailing-edge flaps to enhance combat manoeuvring became both desirable and practicable, but the complication on the leading-edge flaps to sustain combat loads and blowing pressure and temperature proved to be uneconomic. With the increased emphasis on high combat manoeuvrability, and with more emphasis on the fighter role, some alleviation of the high-speed low-level ride was considered to be acceptable. As a result an unblown leading-edge flap was adopted, which reduced the maximum lift coefficient by some 25 per cent, which was offset to retain takeoff and landing performance by a corresponding increase in wing area — which, of course, also improved combat manoeuvrability.

In 1975 the P.159 succeeded the P.153, and, apart from incorporating the increased wing area, looked very similiar. Wing area was 220 sq ft, span 26.9 ft, length 43.7 ft, and basic weight with the Brough-proposed avionics package of 12,700 lb. Fuel capacity as determined from the combat simulations and mission assumptions was 5,500 lb, resulting in a takeoff weight of 19,100 lb in the fighter role, increasing to 26,000 lb with a full load of ground-attack stores.

At this stage we decided to include some of the higher technology which had become more readily available. Fly-by-wire with active controls, an advanced cockpit with multifunction cathode-ray tube displays, and a sidestick were included. To give better tolerance to sustained high-g manoeuvres an articulating ejection seat was included, with the seat back angle extending to 55°.

Redesignated as the Hawker Siddeley 1190, to merge with companion Kingston designs, it was included in the range of solutions offered against the Air Staff Target 396 and, subsequently, in a slightly improved form as the Hawker Siddeley 1204 in respect of the succeeding Air Staff Target 403.

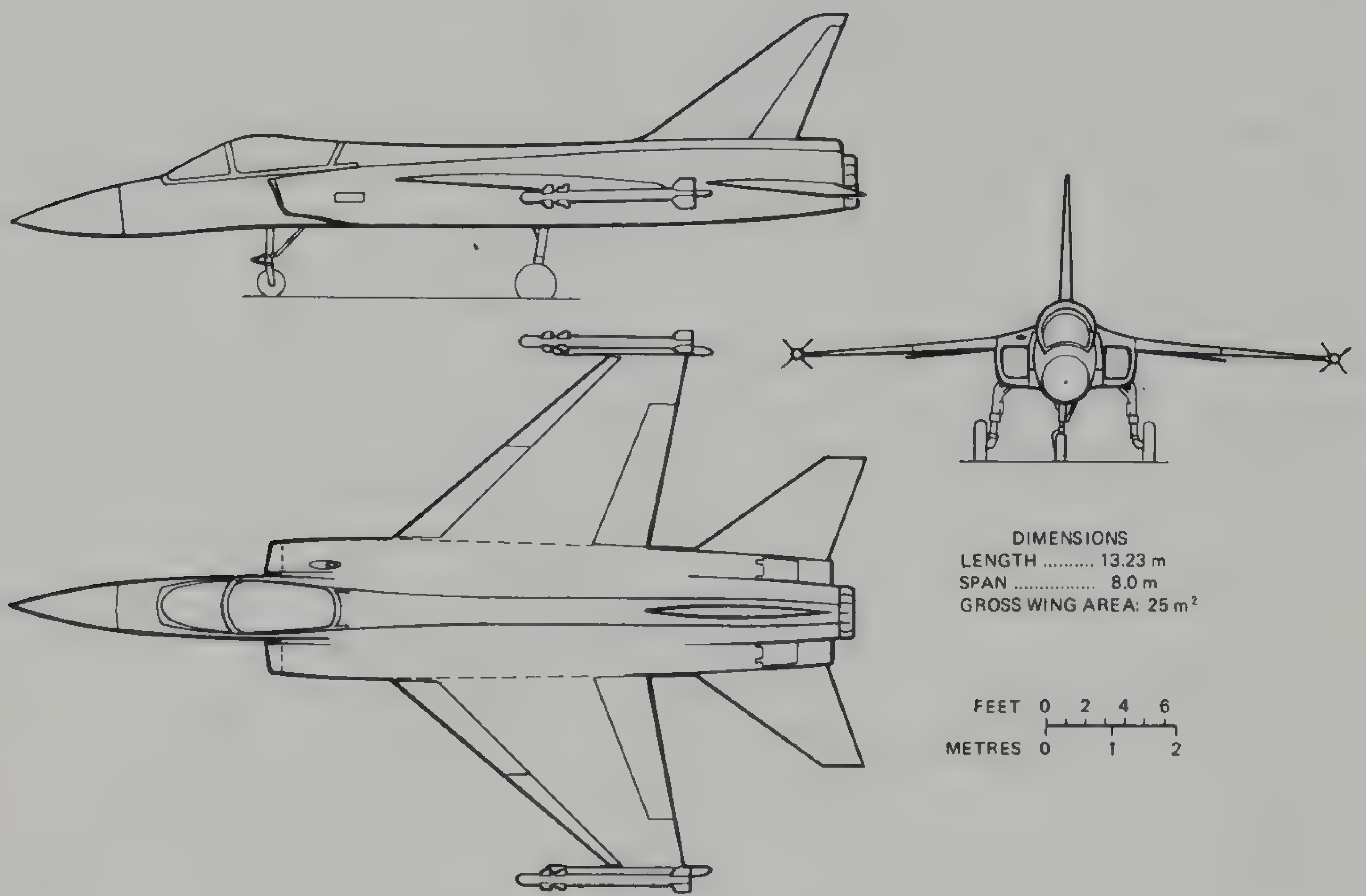
To complete the Brough saga, the same design was developed in 1979 into the P.163 encompassing the more recent developments on composite structures, advanced metallics, active controls and digital avionics. By this time we were part of British Aerospace.

In 1980 there was a resurgence of interest in the lightweight fighter, and I found myself at Warton designing the P.106 series of aircraft. All employed active controls with artificial stability, composite materials for all flying surfaces, the use of lithium-based alloys and superplastic forming and diffusion bonding in areas of metallic construction, together with the extensive use of a digital data bus for the management of the aircraft systems. Both a near-conventional tailed design and the more recent delta-canard made viable by the application of artificial stability were investigated. For a time a joint Brough-Warton team worked together to integrate P.163 and P.106 thinking and experience, and also to cross-check each others' estimates.

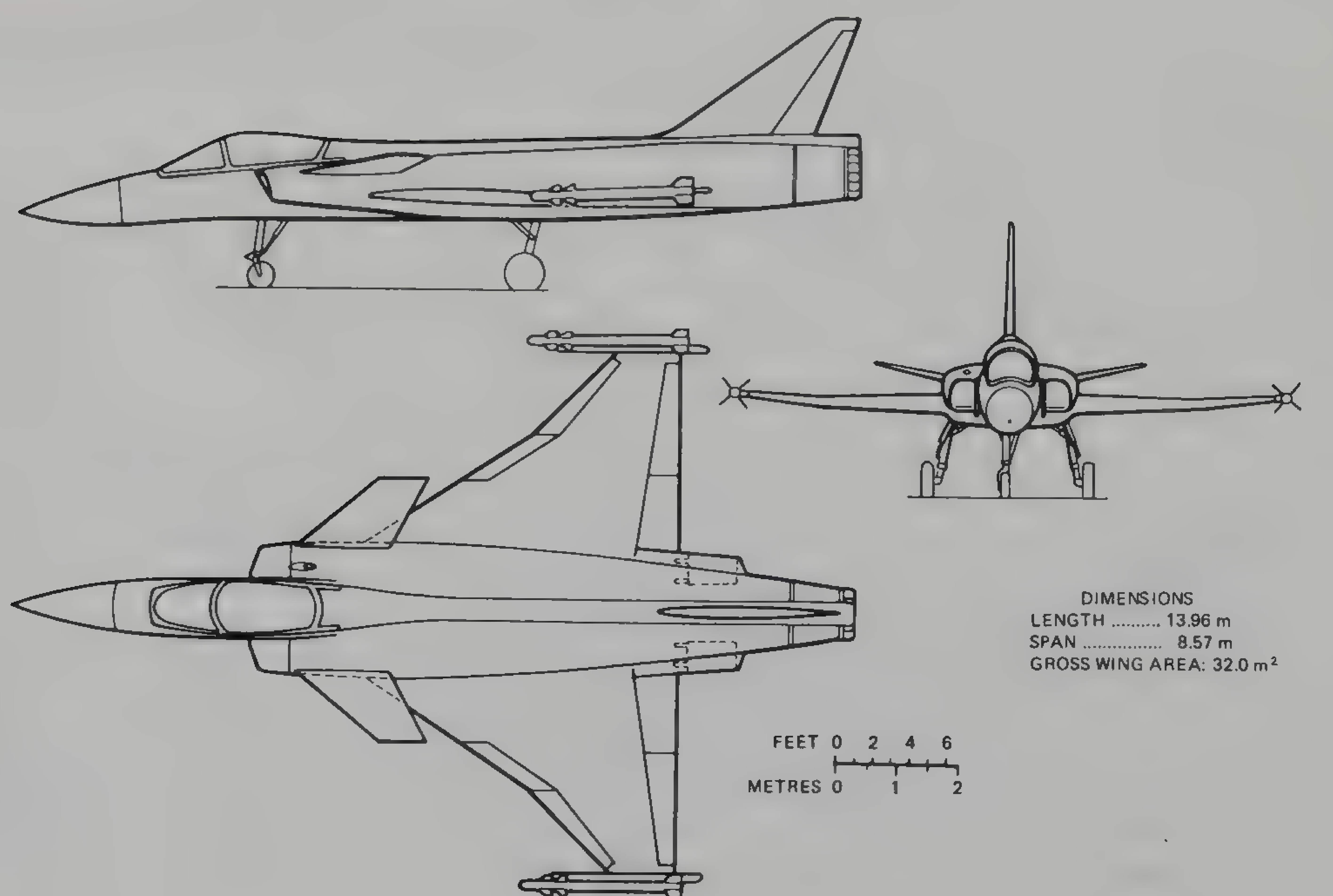
There were interesting levels of both agreement and disagreement. Brough strongly favoured the tailed design, and advocated the use of boundary-layer control and a thrust reverser. In contrast Warton leaned towards the delta-canard, had had unhappy experience with thrust reversal and favoured a braking parachute, and considered that purely mechanical high-lift devices could give adequate performance. There were other detail disagreements, such as the nature of the fuel system, each site favouring the approach used on their previous major project, but on structural concepts, avionic philosophy and

performance estimates there was virtually complete agreement. As a result, a basic design of each of the two configurations was laid down.

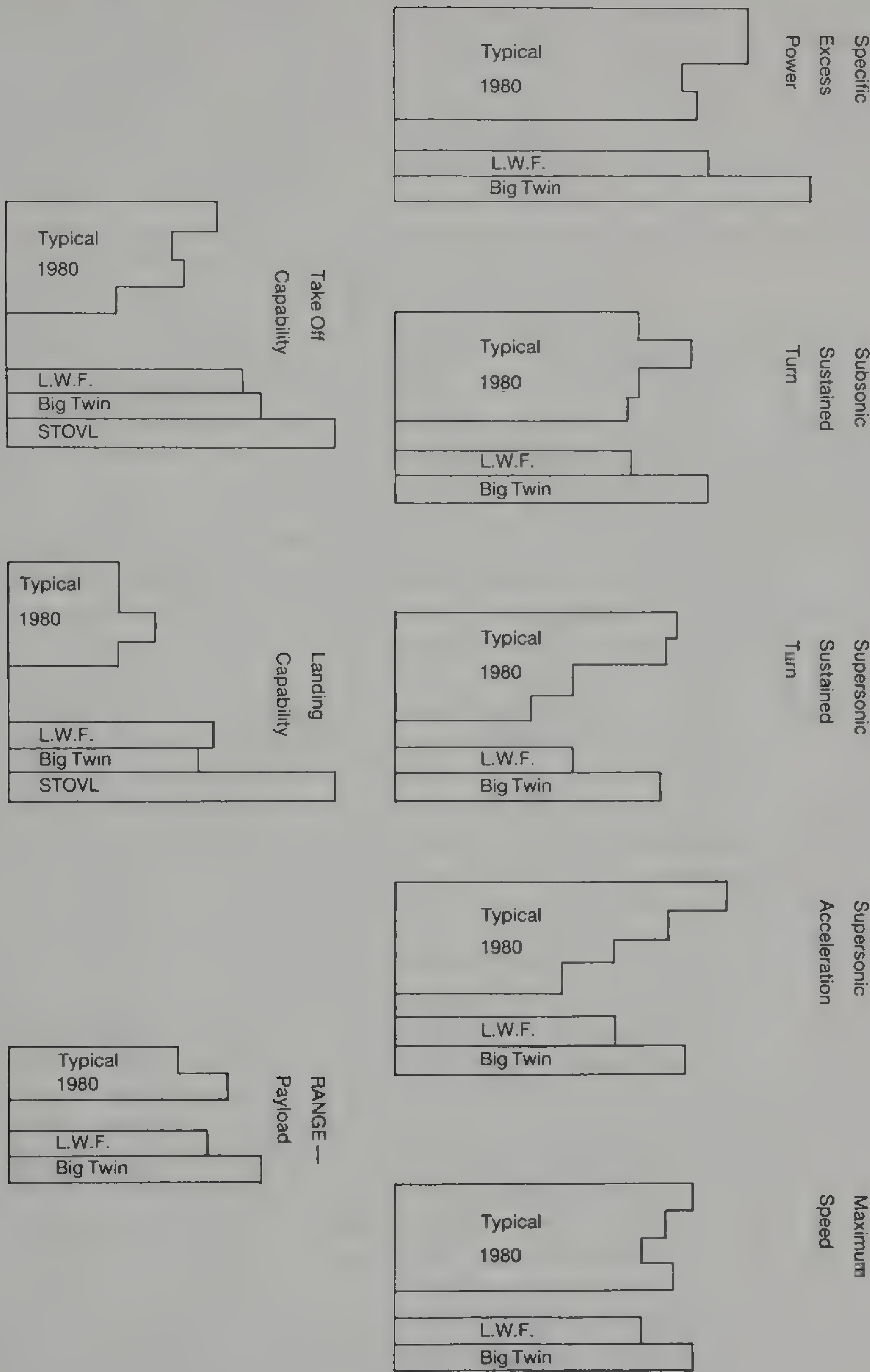
It was a strange position for me, having for eight years previously led the Brough effort, and more so when I was given the responsibility of recommending the preferred configuration.



P.106A — general arrangement.



P.106B — general arrangement.



Lightweight Fighter performance.

At this stage wing area of the tailed design had increased to 265 sq ft, with the delta-canard at 350 sq ft. Basic weights were 13,500 lb and 14,500 lb, respectively and, with fuel loads of 4,400 lb for the air-to-air mission and 5,400 lb for the ground-attack mission, takeoff weights for the two roles were 19,200 lb and 25,500 lb for the tailed aircraft, and 20,200 lb and 26,500 lb for the delta-canard. On performance there was little to choose between the two configurations, there being a degree of 'swings and roundabouts' on specific parameters. What does not show up in a straight comparison of conventional performance figures is, on the one hand, the superior high-AOA (angle of attack) manoeuvring potential of the delta-canard, which would make it a more effective fighter, but, on the other hand, its greater sensitivity to the destabilizing effect of underwing stores which would give the tailed design the edge as a ground-attack aircraft.

The choice between the two configurations must rest on the relative priorities given to the air-to-air and air-to-ground roles, if in fact there is a requirement for both. Requirement or not, it is a virtual certainty that somewhere, some time, such an aircraft will be asked to fulfil both roles.

Quoting Roy Braybrook again, 'It is possible to develop a perfectly good aircraft and offer it at bargain basement price and still find that it is slow to sell because it lacks a brand-new image'. This is a very pertinent factor, and on this count, and on the fact that it must have more unexplored potential, the delta-canard would seem to win the day. This view is clearly shared in Sweden in the form of the JAS 39 Gripen.

In further considering the specification for a lightweight fighter — or as it is now called in India a Light Combat Aircraft (LCA) — the debate moves to the details of the operational equipment: weapons, sensors and associated data-processing equipment. Any modern SRAAM and, with certain provisos, MRAAM can be accommodated for the fighter role. The range of air-to-ground munitions already available or becoming available leaves the attainment of an effective air to ground role no problem, at least from the viewpoint of weapons.

Digital data buses would form the core of the aircraft and weapon management systems. The major problem is what primary sensors should be fitted, and in what combination — internally fitted or in add-on pods. Solutions depend on how the aircraft is to be operated, and on what equipment is available, either technically or, if one is seeking the widest possible market, politically.

In a Royal Air Force type of environment, large two-seat fighters with high-performance radars seem assured of a place in the inventory for the foreseeable future. A lightweight fighter operating in conjunction with these would only need a relatively short-range attack sensor, which could be an already-developed radar or possibly an infrared sensor. The current concept of using the SRAAM-armed Hawk to supplement numbers does so without any such facility. Air-to-ground sensors, of which a wide choice exists, could be fitted in scab-on pods, as and when required.

Smaller nations, for which the LCA could be a primary fighter, might have more demanding radar requirements but, by very definition of their position, be forced to make the best use of whatever is obtainable. Radars developed for the Sea Harrier, the SAAB Gripen and various French equipments could each form a suitable proposition. One can be certain that the ingenuity of man, so often demonstrated, will make the best use of the equipment provided, often in a manner never envisaged by the designers.

The relative performance capability in terms of some of the most significant parameters of an LCA, relative to some of the principal types now in service and also to a new big twin, is shown diagramatically in a chart. The takeoff and landing capability shown is the inverse of the distances required, and the relative value of a typical STOVL aircraft is also indicated.

Comparing the LCA with the new big twin, specific excess power at high speed is 80 per cent, low-speed sustained turn rate 90 per cent with supersonic turn rate and acceleration from high subsonic speed both 75 per cent. Thus, if the very edge of performance is required for success and survival, the deficiences of the LCA are apparent, but at the same time it can be seen to be superior to many of the types which it might meet in combat.

The original P.153 proposals of 1970 offered an in-service date of 1978, a schedule which might have been negated by the subsequent engine development story. The last purely British proposal for an LCA, made in 1981, offered first flight in 1985-86 and in service 1988-89. The only version to be realised at the time of writing is the Swedish Gripen, flown in 1988 and to enter service in the early 1990s. Discussions with India in 1981-82 were based on first flight in 1986, but in 1987 they were still talking with no firm ongoing commitment.

Whether, through all of this, the opportunity for a highly marketable British proposition has been lost is a matter for speculation. The availability of a suitable engine could have been a problem, although both the RB.199 and the General Electric F404 have the basic capability. The F404 has in fact been chosen for many aircraft including the Gripen and the prototypes of the Indian LCA.

In conclusion of this review of projects, it is interesting to reflect on the cycle which has occurred during the time of the recent LCA studies.

The delta-canard configuration of the P.106 owes its origin to the collaborative studies of 1979-80 with MBB and AMDBA which produced the proposals for the twin-engined European Combat Aircraft (ECA) which had followed on from MBB's own studies of the TKF 90 and the joint MBB/BAe European Collaborative Fighter (ECF). The ECA was abandoned by the three governments as non-affordable.

In 1981, following sight of Rolls-Royce proposals for an improved RB.199 for the P.106 LCA, British Aerospace identified a possible market slot for a very-high-agility fighter, put two of these engines into a 30 per cent scaled-down ECA but with a less-ambitious avionic development programme, and began work on a private venture basis, together with a number of British equipment and component suppliers, on the P.110 fighter. Susbsequent attempts to enlist Government and international support resulted in the Anglo/German Agile Combat Aircrat (ACA) proposal.

When this stagnated, the United Kingdom group which had been formed in the P.110 days, with limited but encouraging Government support, worked together on the Experimental Aircraft Programme (EAP) which embraced most of the technology and configuration details which were considered to be appropriate to the next generation fighter. The EAP aimed at putting an aircraft in the sky, although it was recognized that a full project could be undertaken only on an international collaborative basis. Eventually, an ever-increasing number of nations have collaborated on the European Fighter Aircraft (EFA), which seems highly likely to mature. To those of us who worked on the ECA in

1980, from what we know of the proposed EFA, the latter is remarkably similar to the then non-affordable ECA.

Thus, the lightweight fighter studies in the United Kingdom, whilst not having found a niche in the domestic market, have led to international collaboration with several nations who are embarking on a programme of this nature. They have also provided a bridge of continuity between the studies of ECA in 1980 and the EFA of 1986-87.

Beverley XH 123. *(BAL)*

Chapter 5
Birth of the Buccaneer

First gleanings of a forthcoming Naval requirement for a new aircraft were obtained in the late summer of 1953 with the first drafts of the Naval Staff Requirement NA.39, originating for circulation within the official channels over the period July to September. The autumn of 1953 saw industry — about a dozen companies — becoming increasingly involved in discussions with the then Ministry of Supply. Design work started in earnest, with the expectation of the issue of a specification and invitation to tender in early 1954.

However, the essentials became known during the autumn of 1953 and can be summarised as follows:

> Takeoff weight not to exceed 40,000 lb, with overload up to 45,000 lb.
>
> Landing weight 30,000-35,000 lb.
>
> Folded dimensions 51 ft length, 20 ft width.
>
> Normal design weapon load of 4,000 lb.
>
> Catapult and arrester gear limitations defined.
>
> Primary role to be the attack of ships at sea or on large shore-based installations, all of which could be described as radar-discrete targets which should be identifiable at long range.
>
> Primary weapons were listed as: Green Cheese, a large anti-ship homing bomb, and a tactical nuclear bomb.
>
> A large range of secondary weapons was also listed, and the aircraft was to have the capability of operating as a flight-refuelling tanker.
>
> The operational profile envisaged descent from cruising altitude to very low level just beyond anticipated radar detection range, and a high-speed low-level dash to and from the target.
>
> An ambitious radius of action was also specified.

The problem was therefore, within the severe carrier constraints of weight and dimensions, to produce an aircraft with the stipulated radius of action with a high-subsonic performance with strong emphasis on high-speed low-level characteristics and with a large weapons bay capable of use at much higher speeds than had previously been practicable.

Sitting in my corner of the Brough Project Office in 1952, directly after the substantial effort expended on the N.114T fighter, I had attempted to anticipate the need. I had drawn up the initial B.103 design, and had also caused a low-speed tunnel model to be constructed. Of course, at this time missions, profiles, weapons and equipment to be carried were a matter of guesswork.

It seemed obvious that to do a worthwhile job a twin-engined aircraft was necessary, and of engines on which information was available the 11,000 lb Armstrong Siddeley Sapphire ASSa. 7 variant offered the best characteristics.

Wing design followed the previous work, with a straight swept trailing edge and two different angles of leading-edge sweepback, thickness/chord ratio decreasing from root to tip. The aim was to cause the inner wing to shock-stall first at high speed and, with the aid of a slat on the outer wing, to avoid the low-speed tip stall, thus eliminating pitch-up problems over the whole flight envelope. Had this concept subsequently been applied, the evidence is that it would have been successful, but for good reasons it was not to be.

Maximum level speed was not specified, although it was indicated that some value was placed on it. We decided that the aircraft should be free of transonic effects at the penetration speed, which was required to be in the 0.8 to 0.85M range. This would automatically ensure a top speed in excess of 0.9M.

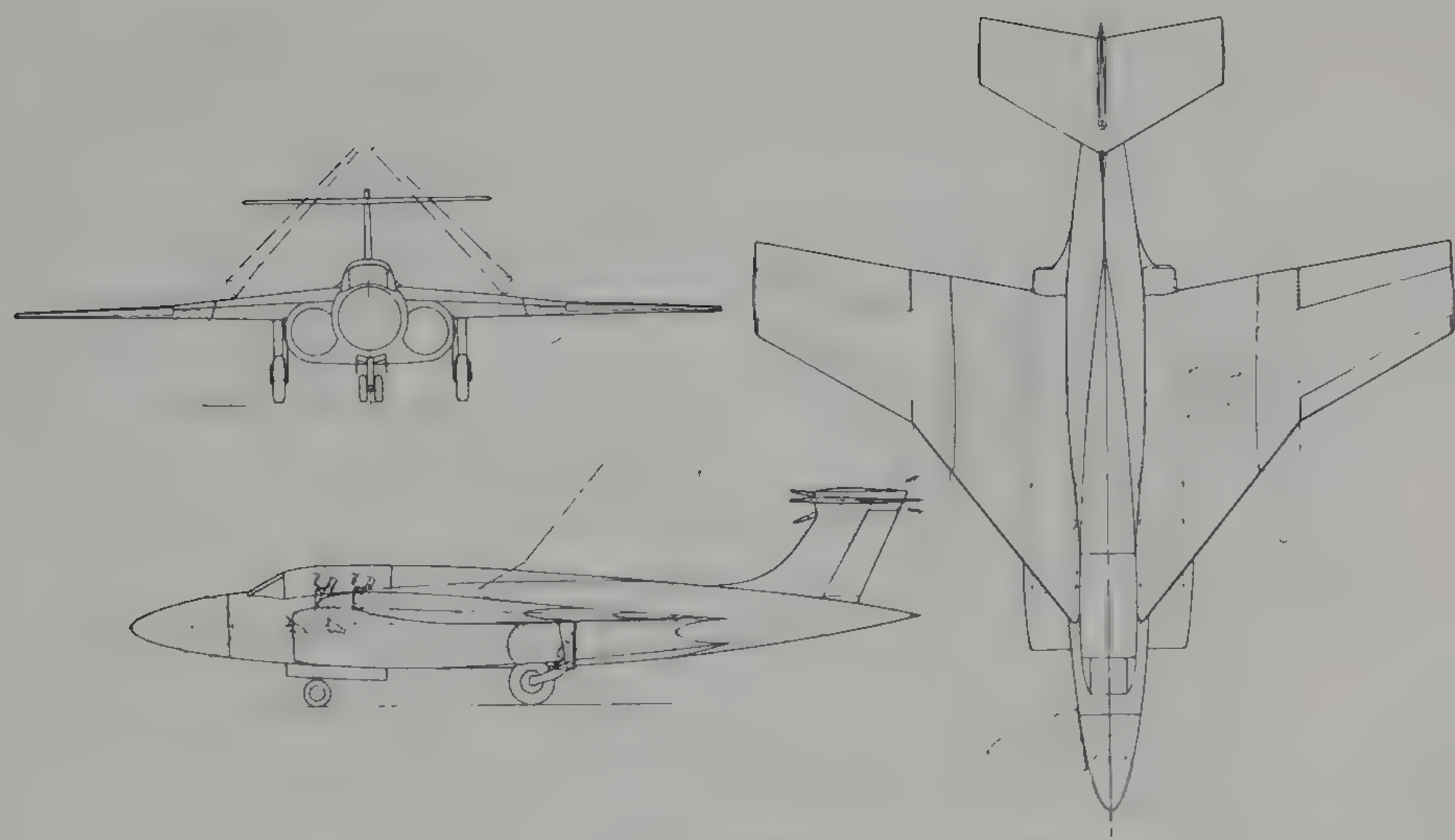
A high T-tail (fin-tip mounted tailplane) was again selected, although problems with such tails, in particular on the Javelin, had hardened opinion against such a configuration. In order to keep the weight down, and ease carrier hangar stowage, there was a strong case for keeping wing area and (particularly) span as low as possible. A span of 45 ft and wing area of 650 sq ft were the maximum if a heavy and cumbersome double wing fold were to be avoided. To achieve this, some form of lift enhancement, particularly on landing, was essential. Results of the jet-deflection Meteor trials had just become available, and this seemed a plausible answer to the problem. Calculations showed that a 60° deflection with the Sapphire engine thrust would reduce approach speed by 25 knots. It could not, however, be usefully employed for catapulting, and the problem of asymmetry on a single-engined landing placed a big question mark against the jet-deflection principle.

Nevertheless, it was decided to prepare a configuration capable of absorbing the jet deflection whilst retaining an open mind on its application. To position the deflected thrust line close to the centre of gravity meant placing the engines well forward relative to the wing. This arrangement was beneficial to structural design, allowing the spar rings to encompass the jetpipe rather than the engines. It was also part of this design to bend the load-bearing structure over the weapons bay. Both these features were retained in the later Buccaneer design.

The original B.103 design is illustrated. As can be seen, in many ways it resembles the Buccaneer, but the staggered side-by-side seating as in the Mosquito and the twin Aden gun installation are significant differences. With wing area of 650 sq ft, span of 45 ft and an estimated takeoff weight, even at the initial project stage, of 42,000 lb, carrier compatibility was at best marginal.

This was the situation at Brough when NA.39 work began in earnest in November 1953. In addition to the design work on the B.103 configuration there was an extensive dossier of parametric calculations and a tunnel model, made some nine months previously, on the model shop shelf and ready to go on test.

Up to this stage, all of the work had been done by one man, but this rapidly changed to three designers, two aerodynamicists, one stressman and one weights engineer. Within three months this had increased to ten designers, five aerodynamicists, two stressmen and the weights engineer, who with the wind-tunnel team saw the tender submission through to the end. Eventually over 1,000 technical staff were to be employed on the Buccaneer.



The B.103 — early general arrangement.

By early 1954 official interest was being shown in a new lightweight engine in the 7,000 to 8,000 lb thrust category. Our parametric studies showed that, with certain reservations, such an engine could be very well suited to the NA.39 concept. If the engine characteristics proved to have the right qualities, something like 5,500 lb weight could be saved compared with the twin-Sapphire arrangement. This could bring the design within the stated carrier limitations, provided that sufficient lift could be generated for takeoff and landing. A wing area of 535 sq ft and span of 42 ft seemed to be the minimum which could be contemplated, so design work proceeded on this assumption, whilst more engine studies and parametric calculations continued in parallel.

Data on blowing engine bleed air over wing flaps, pioneered by John Attinello in the USA, had just become available. Flap-blowing was strongly advocated by Lewis Boddington, whose responsibilities at the Ministry of Supply included the NA.39. The Attinello flap had been flown on a modified Grumman Panther, and application was being made on the Supermarine Scimitar which would give British results in the foreseeable future. Data usable on a project design basis were scanty and unreliable, but Dr John Williams of the National Physical Laboratory took up the cudgels and rendered sterling assistance to enable us to do some serious design work.

The breakthrough which occurred to enable flap-blowing to succeed came with the availability of the necessary quantity of air at a high enough pressure to choke the slits, and hence automatically to get an even spanwise distribution. We deduced from all of the data available that sufficient air could be bled from the engine and that, due to the anticipated engine conditions, landing rather than takeoff would be the critical case for design. With the normal part-span flaps and an outer-wing leading-edge slat, a maximum lift coefficient of 1.4 could be considered to be a fair target. With flap-blowing an increase to 1.7 was guesstimated, and this would give a reduction of some 15 knots in catapulting and arresting speeds.

Purely instinctively, with possible aerodynamic problems around the kink in the planform, together with the discontinuity at the inboard end of the slat, I had a horror of a further discontinuity from terminating blowing at the outboard end

of the flap. I therefore proposed to avoid this and to improve induced drag to extend the blow over whole of the span, with the hope that eventually we could droop the ailerons to obtain effectively a full-span flap. One day our Technical Director, N. E. 'Nero' Rowe, looking over my shoulder, asked what lift coefficient I thought we might get if the ailerons were drooped. Taking a deep breath, and looking into my crystal ball, I said 'About two'. There and then the decision was made to go for it from square one.

A normal flap system would occupy about 65 per cent of wing span. The wing fold break was at around 45 per cent span, so the flap would have to be in two sections. With the ailerons to be drooped, this seemed wasteful, so the ailerons were extended inboard to the fold.

Having got this far in the blowing system concept, we were worried about overbleeding the engine in the event of a failure in the ducting. After much thought we inserted restrictor venturis as close to the engine offtake as possible. This also gave protection for the one-engine-out case, for which a crossfeed duct had been introduced to avoid asymmetric blowing.

Another factor to have a major influence on the design of the system was the insistence of the Naval Staff on full airframe anti-icing. Electrical means available at that time required what we considered to be excessive power. We liked the idea of using hot engine bleed air, but it could not be ducted into the leading-edge slat. However, if the leading edge was fixed, an aft-facing slit on the upper surface at 1.5-2.0 per cent chord would enable bleed air to re-energize the airflow in the same manner as the slat, while the ducting to achieve this could also be adapted to give the anti-icing function. This was the solution adopted, although the final result was rather complicated. The inner-wing leading edge had also to be deiced, and the trailing-edge blowing shut-off in the anti-icing mode. As bleed pressures at higher than takeoff and landing speeds would equally be higher, a pressure-regulating function was also necessary to protect the very hot pressurized ducts.

There were also problems to be solved with the tailplane. Blowing over the flaps could increase pitching moment by 80 per cent, and with blown flaps and drooped ailerons on a swept wing, pitching moment is trebled compared with the conventional unblown part-span flap. This adds two problems. The peak lift to be generated by the tailplane is greatly increased, and there is also the need to deal with the large change of trim associated with flap selection. A trailing-edge flap on the tailplane geared to flap and droop selection can counteract the trim change, but, as tailplane load increases with decreasing speed, it would increase the tendency for a leading-edge stall on the 5 per cent thick tailplane. This stall problem was dealt with in a similar manner to that of the outer-wing leading edge. The tailplane anti-icing duct was modified to form a blowing slit, but in this case, because of the direction of the load, on the under-surface.

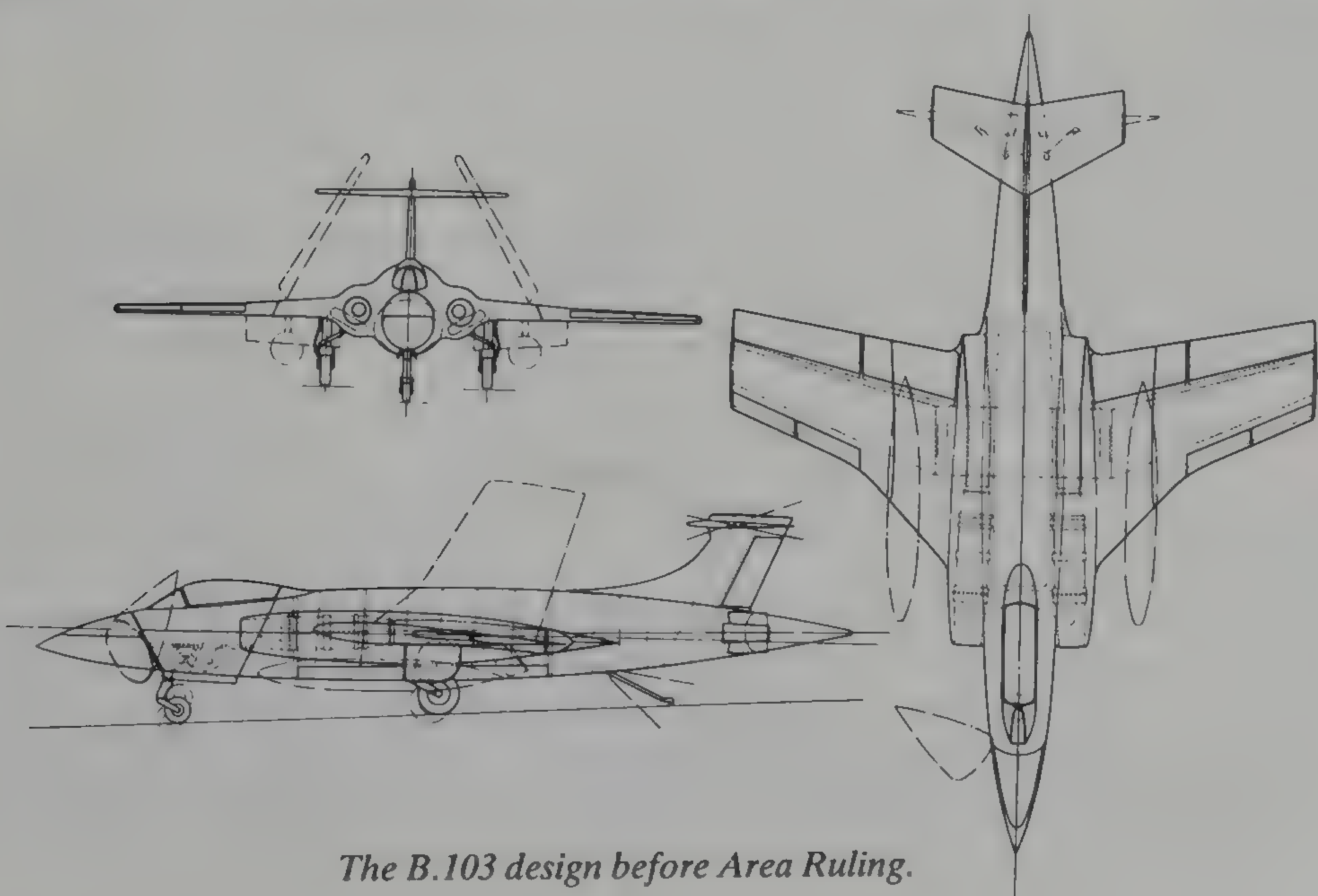
Having got this far with the design of our high-lift system entirely on paper, manufacture of a 1/5th-scale half wing was begun, with both trailing- and leading-edge slits in an attempt to substantiate our assumptions before the tender was submitted. The agreement lately concluded by Blackburn with Turbomeca led to a Palouste engine being available on site to deliver the air for the flap blowing, although in later years, following the construction of a high-speed tunnel, the air was drawn from the tunnel reservoirs. We generated the data just in time, and the results looked encouraging but, as there was a degree

of uncertainty due to scale effect, we could not be certain. Interpretation by experts at Farnborough seemed to confirm that our estimates would be met.

It is worth noting that this radically new system was developed while we did not have either a definitive airframe or engine. Of the air bled from the engine for boundary-layer control, 75 per cent was discharged over the wing trailing edge, 15 per cent over the outer-wing leading edge and 10 per cent over the tailplane leading edge. In addition to the air bled for boundary-layer control, a permanent bleed about 1/6th as great is taken for the various aircraft services.

Throughout the initial project design phase, the choice of engine was constantly causing difficulty. All the parametric calculations were based on scaling Sapphire ASSa.7 data, and these showed this 11,000 lb engine to give too heavy an aircraft to meet the specification but that a 7,000 lb scaled version would be ideal. In this connection the meeting of the specification must be emphasized. Whilst all performance and weight limitations were met with a 7,000 lb engine, it seemed clear that a 10,000 lb-11,000 lb engine would give a better all-round aircraft.

At a meeting in London on 4 December 1953 Rolls-Royce outlined a requirement which had been circulated by the Ministry of Supply for a new lightweight engine, issued on 16 November, and which included the NA.39 among the possible applications. Thrust was to be in the 7,000-8,000 lb bracket, and type-test was required to be completed in 2½ years. Rolls-Royce had in hand a proposal which might be suitable, but with their other commitments they had some doubt about whether to undertake this programme. The proposal would give a thrust of 7,000-7,500 lb and had a specific fuel consumption and other characteristics very similar to those we were seeking. Definitive design of the B.103 then proceeded on the basis of this engine, with the result as illustrated of an aircraft with a wing area of 535 sq ft, and a span of 42 ft, which was very similar to the final design. Unfortunately, in January 1954 we heard that Rolls-Royce were not to proceed with the engine, and we found ourselves in some disarray.



The B.103 design before Area Ruling.

Two other engine firms, de Havilland and Armstrong Siddeley, responded to the Ministry request. The de Havilland proposals, as presented to us in January 1954 by Dr Eric Moult and Frank Owner, were for an 8,000 lb scaled version of the Gyron, later to be known as the Gyron Junior. This, in the form submitted, proved to be quite unsuitable, the combined weight of engine plus fuel being well over the maximum needed to keep within specification limits. It seemed to us that derating the engine to 7,000 lb and running at a lower temperature would be a move in the right direction. This, and some redesign of both compressor and turbine following a major effort by de Havilland, produced the much more favorable Gyron Junior PS.43 proposal. In the end this proved to be the best that was available, and fitted in reasonably with the aircraft design which in the meantime we had of necessity continued to pursue.

An enormous air bleed of some 12 per cent of engine mass flow was now being requested for boundary-layer control. Whilst the engine was capable of giving this, maximum thrust with this amount of bleed would be reduced to 6,000 lb, which was inadequate. Fortunately, the decision to derate the engine to a reduced temperature came to our rescue, for reverting to the original high design temperature in the 'blow on' case reduced the thrust loss, although with some complication in the engine control system, such that thrust did not fall below 6,500 lb. Later in the development programme turbine blade cooling was introduced, used only in the 'blow on' mode, when the full value of the unblown thrust was achieved.

The Armstrong Siddeley P.151 proposal was presented to us in early March 1954. Whilst the weight of the engine plus mission fuel was competitive, the engine had unusual characteristics in its variation of thrust with forward speed which would seriously affect the combat performance of the NA.39, and on this basis it was rejected.

In the meantime a proposal from Bristol for the BE.33 engine of 11,400 lb thrust had become known to us. Larger and heavier than the Gyron Junior, but with quite good fuel consumption, it gave a combined weight of engine and mission fuel some 10 per cent greater, but nevertheless seemed attractive and more adaptable to our air-bleed requirements.

We summed up the engines at the time of our submission:

> 'The Gyron Junior gives the aeroplane which is lightest but which meets the specification in all respects and exceeds it in performance, whilst the BE.33 gives higher performance at the expense of increased but probably acceptable weight.
>
> 'The Gyron Junior PS.43 is ordered and, as it is a scaled-down version of an existing engine, its development should be straightforward. It is realistic to expect type-tested engines when required for a prototype aeroplane.
>
> 'At the time of writing, the BE.33 design and development programme is not settled, and it may need a longer time for development. From a technical point of view it has great attractions, in that it considerably improves the performance and extends the scope of possible duties for the aeroplane. It should be more adaptable to supplying air for the boundary-layer control.

'The BE.33 remains of interest, and should be reconsidered for production aircraft.'

It was intended to make the airframe capable of receiving either engine, but with the firm commitment for the Gyron Junior to be built and the predicted delay in the availability of the BE.33 of at least one year, the Gyron Junior PS.43 became the basic engine for the B.103. Later the possibility of installing the BE.33 was eliminated, when, with the heavy accent on weight-saving, the spar rings were tailored exactly to the Gyron Junior jetpipe, the BE.33 pipe being of 3 in greater diameter. In the event it did not matter, for the BE.33 never materialized. (Subsequent evolution of the Rolls-Royce Spey and its fit into the Buccaneer Mk 2 is described later.)

While the engine situation continued to leave doubt on the final airframe, design work continued although we were plagued with uncertainty on the equipment to be fitted. The Naval Staff had been forward-looking in their ideas, to the extent that much of the equipment specified was still in the embryo stage.

The performance of the radar was not in doubt: long-range detection of 'sore-thumb' targets and a ranging function for the final attack, which at that stage was thought to require two radars. In fact the selection of the Ferranti Blue Parrot which fulfilled both roles was not made until much later in the programme, and it was fortunate that the designers were able to accommodate it without undue trouble. A new and advanced pilot's display was envisaged, with modern analog computing of the necessary references. A new lightweight doppler was to be a major navigation aid, and VHF (later UHF) and HF radio were specified.

As a result, in spite of a series of meetings with government officials and equipment suppliers, a good deal of guesswork was required and a fairly sizeable contingency placed on the equipment weight information which had been supplied to us.

As far as armament was concerned, we were working on a more satisfactory basis. For some of the stores listed, and considering the flight envelope involved, it was obvious that internal rather than external carriage would be at least highly desirable and possibly essential. Within the proposed internal weapons bay seven stores stations would have to be provided: a central one for the named large stores, two side-by-side at roughly mid-length for the medium-sized stores, and four in pairs side-by-side to carry four 1,000 lb bombs. The dimensions of the bay to accommodate all of these was readily established — but then the problems started. The large anti-ship homing bomb had to be presented externally before release to enable it to acquire the target, but the aircraft speed at this point in the mission would not necessarily be high. The other stores, some of them of low density, would be released at high speed, in some cases 200 knots faster than had previously been the case.

The traditional bomb bay with stores suspended from the roof was aerodynamically unacceptable, and in any case would not give the pre-launch conditions essential for the anti-ship homing bomb. We considered an arrangement similar to that used on the French Vautour, with inward-tracking doors and the roof lowering to meet the requirement of a shallow bomb bay, but finally favoured mounting the stores on a 180° rotating door, as was done on the Martin B-57 Canberra and Mcdonnell F-101 Voodoo. This left one major problem: the degree of external presentation of the homing bomb. This was

solved by the use of a rack and pinion to lower, as well as to rotate, the door. In the event, the homing bomb was cancelled at an early stage of the project, so the bomb door went ahead with a simple hinge.

Whilst we were happy with the anticipated aerodynamic conditions with the bomb door open or closed, there were doubts about conditions during rotation. Our rather pragmatic approach was to effect the rotation very rapidly, and hope that no noticeable effects could develop. In this we were successful. Two problems which arose from the high aircraft speeds were the need to develop guns to eject the stores forcibly to achieve acceptable separation characteristics, and to incorporate an improved potting compound in the stores' electrics. Both were solved during the programme. A 90° position of the door was provided, to give access for ground servicing of the many aircraft ancillaries mounted on the sides and roof of the bomb bay.

Installation of an Aden gun pack for alternative roles was included in the original specification. For this it was proposed to remove the bomb door and replace it with the gun and ammunition pack at the forward end of the bay, the rear portion being available for the stowage of additional fuel or ammunition. For some reason this did not go ahead, and the Buccaneer has never carried guns, although over the next twenty years we were to make several proposals for this.

To meet the flight-refuelling tanker requirement it was proposed again to remove the bomb door and to offer up into the weapons bay a pack which included the hose and drum unit and also a substantial quantity of additional fuel. Work on this pack was later abandoned, but the Buccaneer has frequently operated as a flight refuelling tanker with a wing-mounted Flight Refuelling Mk 20A pod.

To finalize the initial design, details of the aerodynamic configuration had to be settled. This included enlisting the support of various government specialists, and to this end a series of meetings was arranged at the Royal Aircraft Establishment at Farnborough. The kinked planform with 40° quarter-chord sweep inboard, reduced to 20° at 55 per cent semi-span, and with a 10° swept trailing edge was, after discussing the spanwise variation of wing section and thickness and the introduction of some forward camber, agreed by all as being eminently suitable against the requirements. Nevertheless in these discussions the wing slat had not been replaced by the blowing slit, and test results produced in the Brough low-speed wind tunnel showed the slats to have the desired effect.

Tailplane position remained the most contentious subject. Low or even mid-fin positions would avoid a stable stall, but each had serious disadvantages on the B.103 layout. We had studied the problem, particularly in the context of the Javelin accidents and had come to the conclusion that, following a tip stall with very little loss of total lift, the combined effect of increased downwash over the tailplane arising from the transfer of lift inboard, coupled with blanking effects due to the high AOA reached, would indeed lead to the non-recoverable conditions of pitching moment and control inneffectiveness which had been encountered. Delaying the tip stall, and hence inducing the inner wing to stall first, appeared to prevent difficulties from arising. Using aluminium plate to simulate the thin fin and tailplane, we produced supporting evidence for this theory, such that the high tailplane position was agreed. The substitution of the slat by a blown slit, which operated only when the high-lift configuration was

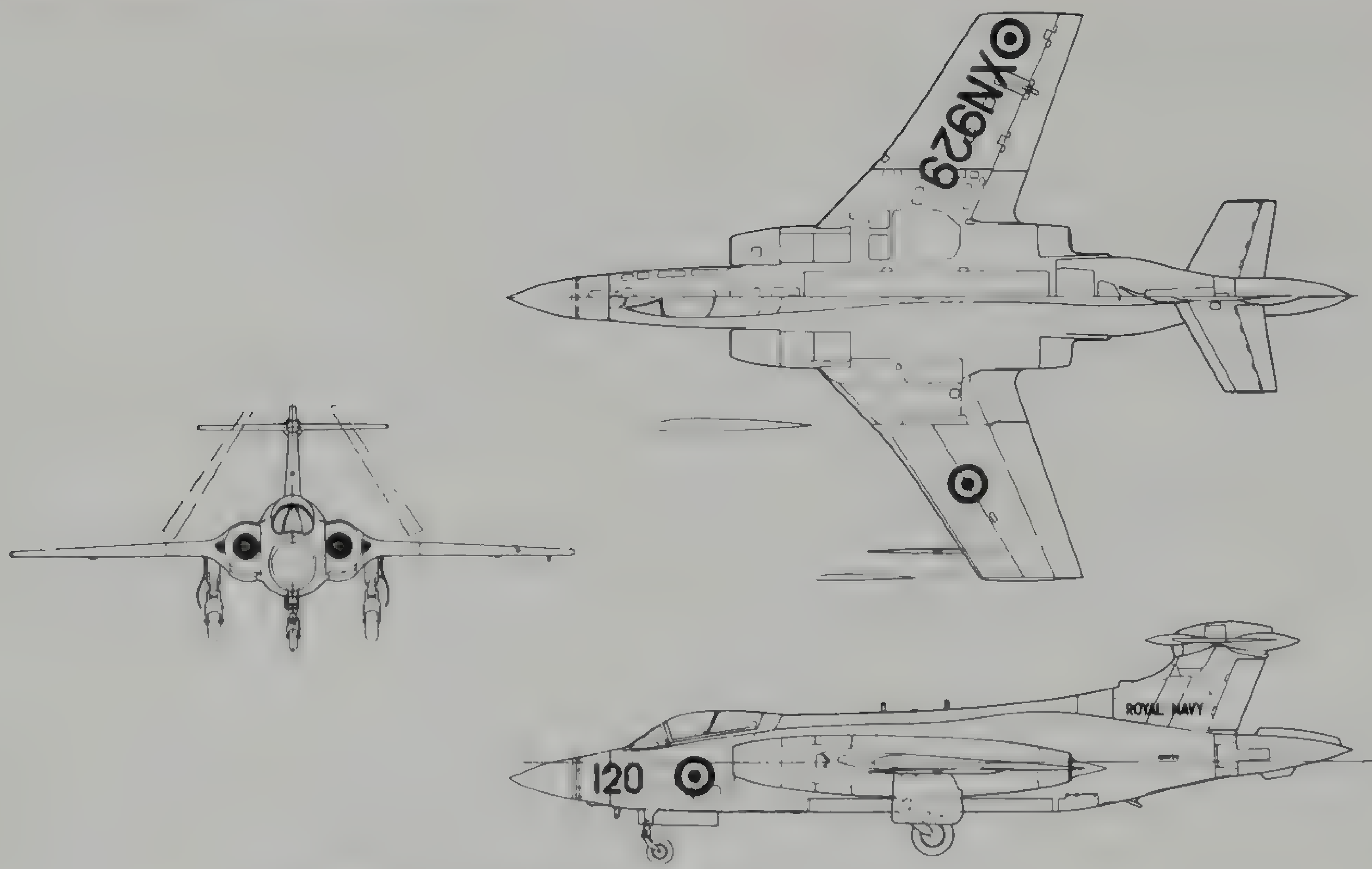
selected for takeoff and landing, did leave a mid speed range where an automatic slat, as originally envisaged, would have protected against tip stall. The absence of any outer-wing leading-edge device did subsequently lead to a few undesirable incidents before safety precautions were introduced with an audio warning from the AOA-sensing apparatus, which was fitted during the development phase to assist deck takeoff and landing.

The probable manoeuvring boundaries of the wing were also agreed with RAE and, in the event, proved to be reasonably accurate although buffet onset came earlier than expected. This was dealt with by an extensive course of vortex generators to settle which a flight test programme was mounted, the intensity of which caused some feelings of revulsion.

The discussions at RAE also touched upon the essentials of the flying controls, based on their experience on — among other things — the Boulton Paul P.111 delta, whose programme had been specifically planned to explore this topic. The most important concerned the tailplane where, with the demonstrated desirable limitation of stick travel, the total movement of tailplane which was necessary would have to be obtained by a combination of stick movement and trim motor. A stick gearing varying with V (airspeed) was recommended, although in the event we provided a non-linear stick gearing with an approximately V feel system. RAE experience showed that autostabilization about all three axes was desirable, and that, if possible, this should be integrated with the powered flying controls. It was suggested that this could be achieved by using electrical signalling from the stick via a potentiometer. This idea, pioneered by Boulton Paul, proved to be impracticable at the time. More than 20 years later the FBW (fly by wire) idea became common practice, although today the input signal from the stick is by force measurement rather than by potentiometer measurement of displacement.

Shortly before completion of our B.103 submission preliminary information on the application of the area rule became available, and every encouragement was given to us to take advantage of it. The precise mathematics were not then known and, even if they had been, there was no time left to apply them. From the information available, it was apparent that the best area distribution corresponded to a symmetrical sine curve, and that, failing this distribution, two half-sine-wave curves would give a reasonable result. We plotted our area distribution for the Mach 1 case (the normal cross-sectional area perpendicular to the longitudinal axis) and then set to work on it. As drawn, it was both bumpy and peaky. The region along the weapons bay was of necessity of constant cross-section and inviolate. We also, on the basis of normal aerodynamic considerations, laid down limits on the rate of change of shape. Pulling in the sides of the forward fuselage to compensate for canopy area was one step taken, and the peak arising from the wing was reduced by increasing the trailing edge sweep from 10° to 20°, with other geometric adjustments to suit. This then left minor changes to the lines of the upper centre-section fuselage to be effected, after which the bulging to fill the gap in area distribution behind the wing, with waisting to accommodate that arising from the empennage, completed the exercise.

The result was very close to a two half-sine-wave curve distribution, with the peak at about 40 per cent aircraft length. It might be debatable whether this materially improved the aircraft's performance where it mattered, but the rear-fusleage bulge greatly eased the problems of installation of much of the elec-



The Buccaneer Mark 1 — general arrangement.

tronic equipment. This major transformation was accomplished in a matter of days.

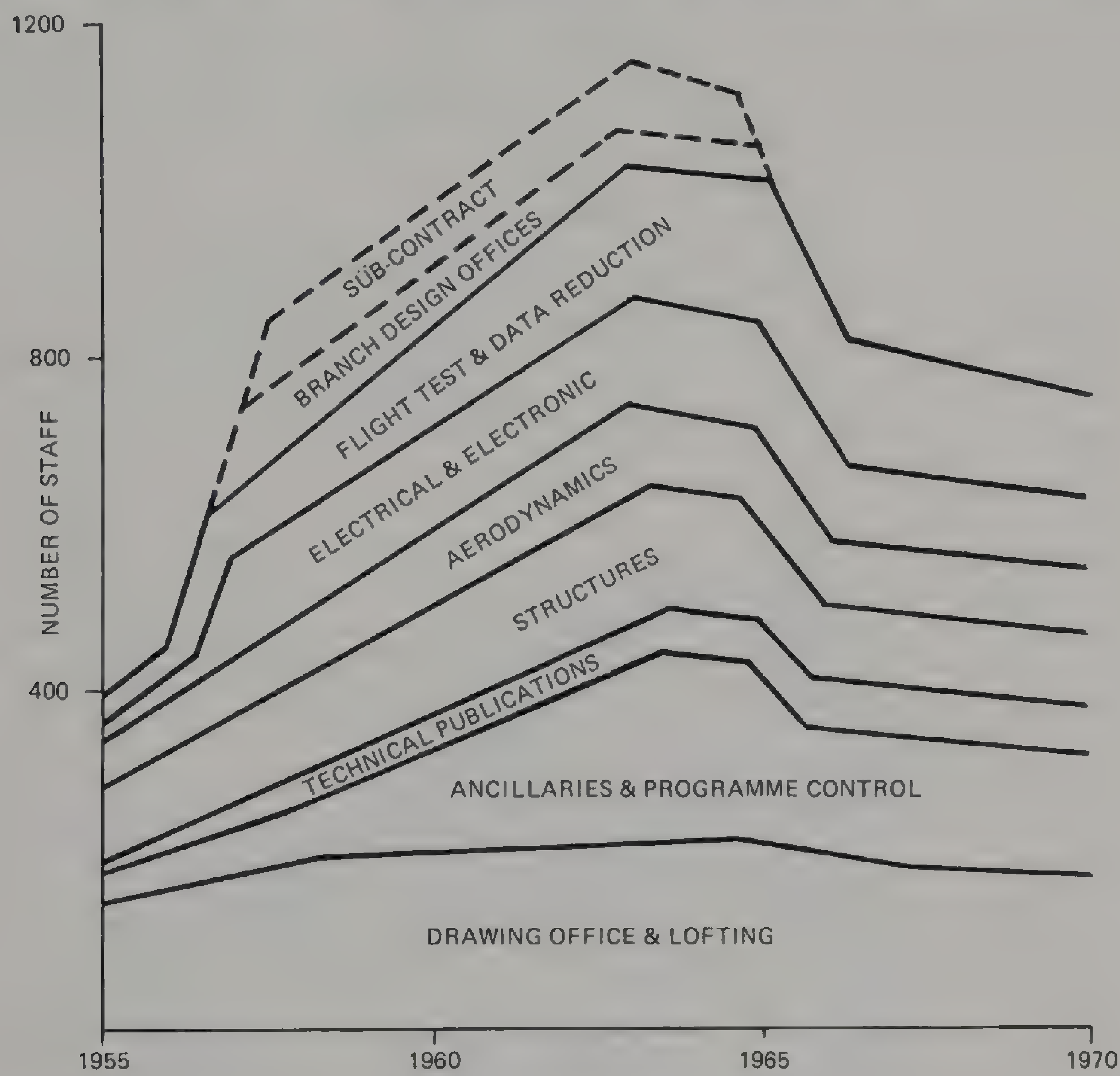
One other area of aerodynamic design which caused concern was the matter of the dive brakes. A very severe requirement had been stated, which called for a drag increase much higher than anything previously achieved. No way of even approaching the target figure was possible by the conventional wing or fuselage side-mounted brakes. Eventually, the splitting of the rear fuselage, with the brakes sliding on a crosshead together with drag links, was selected. Whilst this did give a very high drag figure, and seemed to be the best attainable, even this needed a relaxation of the original requirement, with it was hoped, little trim change. This hope was not fulfilled, and so involved another flight development saga.

This arrangement did, however, produce two valuable side benefits. Moved to the wide open position on the carrier deck, the airbrakes considerably eased the stowed length requirement. The other benefit affected aerodynamic conditions on the landing approach. With the high lift coefficients generated with boundary-layer control, the approach speed was falling below the minimum drag speed. Drag is generally thought to increase with speed, but it contains two terms, the profile drag (which does increase with speed) and a lift-dependent term which increases with decreasing speed. At minimum-drag speed the two terms are equal; below that speed, total drag increases with decreasing speed such that the pilot has a changed relationship between stick and throttle movement, and precise control — as is needed on a carrier approach — becomes very difficult. Increasing profile drag with airbrakes reduces the value of the minimum-drag speed. In our case it brought it sufficiently below the approach speed and, at the same time, increased the overall drag. This meant more thrust was required, and hence higher mass-flow and pressure was available from the engine, to the benefit of the boundary-layer control system.

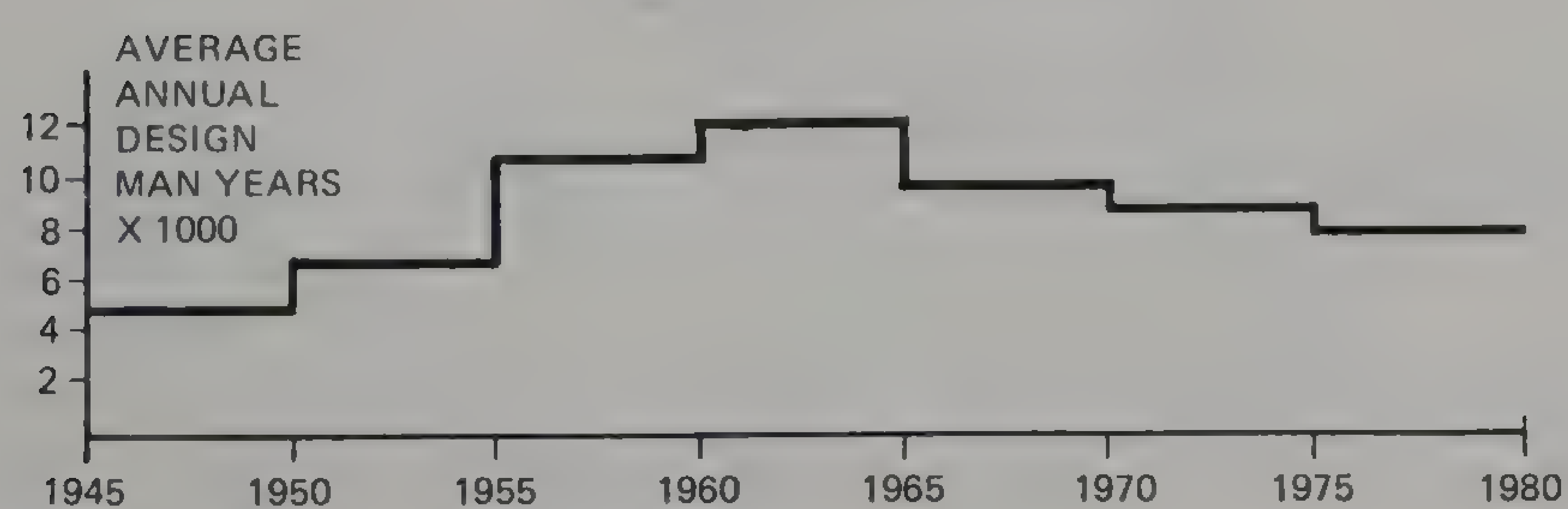
We completed preliminary design work in July 1954. A brochure, produced to

an editorial and presentation standard not seen before for such an application, was prepared and accompanied the Blackburn B.103 submission in respect of NA.39. During the months following the submission, meetings and grillings followed one another, but by the end of the year it appeared that we had won the competition. This was confirmed in July 1955 by the placing of a development contract.

A sizeable design effort had been retained on the B.103 during this period, but this had now to be rapidly expanded to complete the detailed design to a very tight programme. The magnitude and nature of this expansion is illustrated. The development contract encompassed new procedures. In place of the traditional — say two or three — prototypes, a development batch of 20 aircraft

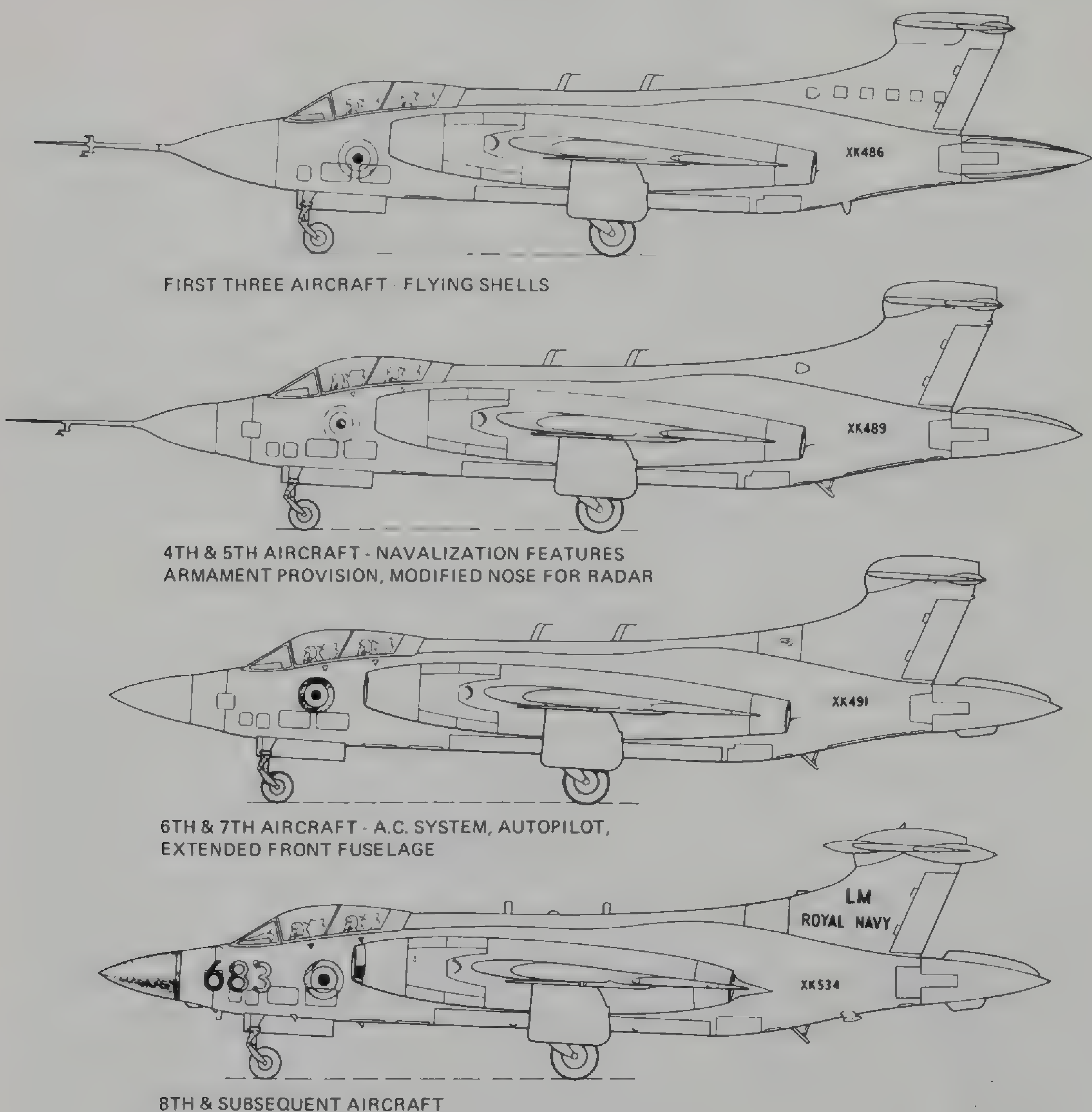


Growth of design organisation.



was ordered, of which nine were for development flying by the firm, five were for clearance trials at A & AEE at Boscombe Down and the remaining six for service trials in the Royal Navy. The weapons-system concept was also applied, where the prime contractor took much greater responsibility for the total product than had hitherto been the case. Extensive liaison with suppliers, and the construction and operation of systems rigs, formed part of the growth load, to which were added the complexity of the aircraft and the beginning of the large-scale use of both analog and digital computers.

Whilst the number of draughtsmen who actually produced the drawings for the shop floor increased by some 60 per cent, the size of the technical staff as a whole trebled, while the ratio of the traditional technical support to the draughtsmen of aerodynamicists and stressmen actually fell by 12 per cent. The spectacular growth was in the electrical and avionics areas, reflecting not only the increased content of these items in the airframe but also the newly distributed weapon-system responsibilities. These included the need for ancillary and

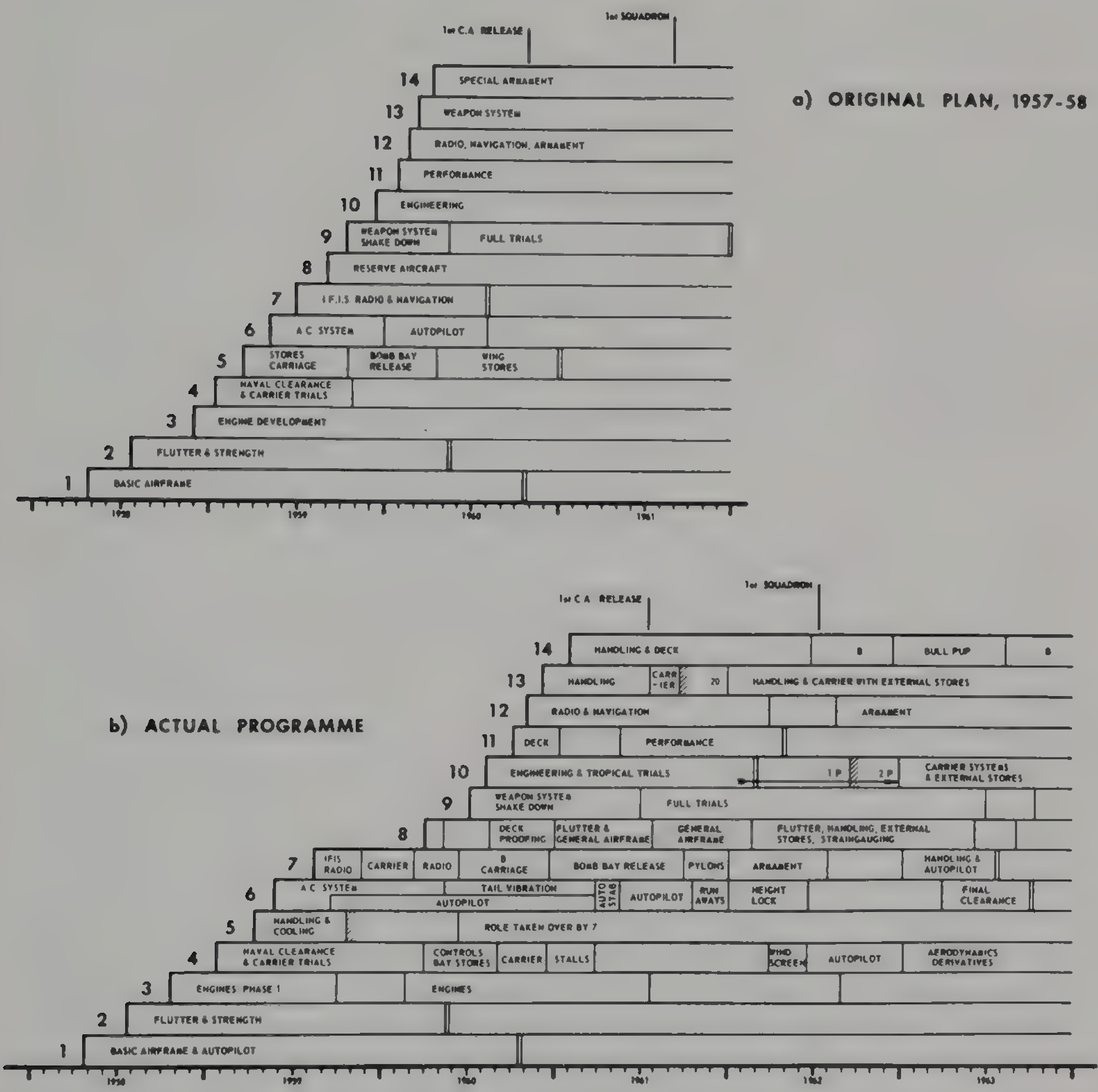


Development aircraft.

control staff to liaise with suppliers, maintain the essential records, and manage the programme. This evolution later became typical of the industry.

From placement of the contract until first flight much detail attention had to be given to the planning of the flight development programme. Decisions made in the build programme themselves had a major impact on this planning.

The first three aircraft (XK486-488), the last of which was allocated to the D H Engine Co, were built as highly instrumented 'flying shells' for proof of the



Development programme.

basic airframe. The fourth and subsequent aircraft were to contain those elements necessary for shipboard operation and also for stores carriage and release. Electrical systems compatible with the final navigation and weapons systems would be introduced on the sixth aircraft, the complete systems coming in on the ninth aircraft to complete the development phase.

More specific roles had to be planned within the limitations of the fleet build, estimates of duration and sequencing of the various elements made and assembled to give a coherent programme. Statistics at the time indicated that, at

best, an average rate of flying of ten hours per aircraft per month could be achieved, and also that — on a prototype-aircraft basis — there was a real risk of losing one aircraft in three during the programme.

It was on this basis that we drew up the intended long-term programme, an outline of which is illustrated. Within batches of three in sequence of build there was sufficient slack to make up for the loss of one of each trio of aircraft, but the loss of two within the same batch would have serious consequences. The one exception to this was the second aircraft, which had to contain elaborate instrumentation for flutter and strength testing. Fortunately no such misfortune befell us, but with the inevitable mishaps the flexibility built into the original programme was fully utilized before we finished. It proved to be just adequate.

Chapter 6
The American Connection

One of the major acts of support from the USA to assist projects within individual nations of NATO which might not be able to enlist adequate internal funding was the Mutual Weapons Development Program (MWDP). This assisted a number of projects, which included the NA.39. Included in these arrangements was access for the US authorities to all of our project data.

It was under these terms that, in early 1957, we hosted a strong delegation led by Charles Donlan, a senior official of the NACA (soon to become NASA) acting for John Stack, and including Lieutenant-Commander Bob Young from the US Navy Bureau of Aeronautics, who was to act as link-man over a considerable period.

For some two days we were well and truly put through the technical hoop, at the end of which they appeared to be satisfied that the NA.39 project was soundly based. They informed us that a similar operational requirement was in preparation for the US Navy, and this led us to hope that our NA.39 project might penetrate the USA in a manner similar to that achieved by the Canberra, which appeared there as the USAF Martin B-57. This was not to be because, having weighed up everything we had told them, the knowledge gained was applied to a rather different project which emerged as the Grumman YA2F (later A-6) Intruder.

The YA2F-1 prototype first flew in April 1960, two years after the Buccaneer. Empty weight, takeoff weight and internal fuel capacity were of a similar order, as was wing area. With a span of 53 ft, compared with 44 ft, a length of 53.5 ft compared with 63.5 ft, and a sweepback angle of 25° compared with 40/30°, the Grumman design was of a radically different shape, with less emphasis on high transonic speed performance. Initial engine thrust was 8,500 lb, compared with the 7,000 lb of the Buccaneer, increasing with time to 9,300 lb, which is rather less than the 11,000 lb of the later Buccaneer Mk 2.

Like the Buccaneer the Intruder has virtually full-span flaps, but without boundary-layer control. Lateral control is from spoilers forward of the flaps. As with the NA.39, jet deflection of 30° was considered and was in fact included on the YA2F prototype before being discarded for A-6 production aircraft. From the start the A-6 had a much more advanced avionics system than the NA.39 and, apart from the introduction of electronic warfare variants, it has also had the advantage of a series of updates over many years.

The decision was taken at the time of the visit, however, to assist our own project by making available to us two very relevant areas of American expertise. The first area was the manufacture and testing of aeroelastic tunnel models for

the determination of flutter speeds. The centre of activity for this was at NACA (NASA) Langley in Virginia, with model design and construction facilities and a blow-down transonic tunnel. This latter was necessary as, should the model disintegrate due to the flutter, the fragments would pass harmlessly away, whereas in the conventional closed-circuit tunnel they could do serious damage. After the initial tests were done at Langley, the Brough model-makers mastered the necessary techniques. The commissioning at Brough in 1956 of a transonic blow-down tunnel enabled all subsequent work to be done in house in a manner and in a facility which remains in use over 30 years later.

The second area was data-reduction equipment for the analysis of flight-test results. Three separate techniques were planned, trace recorders for most data, magnetic tape for dynamic data such as flutter testing, and film for weapon release. Suitable equipment for all three modes existed in the USA. Whilst any equipment supplied was based at Blackburn, the arrangement was strictly government to government. Thus, whilst we could choose and recommend the equipment to be supplied, the Ministry was responsible for any action.

In April 1957 two visits from Brough took place. Colin Saunders and Pip Piper visited Langley to effect the necessary arrangements for flutter testing. On the flight-test side a party of three, chief designer Barry Laight, electronics expert Harry Fuchs and myself made the tour to coincide with a symposium on flight-test instrumentation held in the Statler Hotel in Los Angeles. Harry and I preceded Barry, Harry going to San Francisco to visit Ampex and others concerning magnetic tape, and I went to Washington to make arrangements with the British Joint Services Mission (BJSM), after which the three of us were to join up in Los Angeles for the symposium. We were then to have discussions with Benson-Lehner on their data-reduction equipment, and also to visit Edwards Air Force Base, to see some flight development action. Then we were to go to Washington (BJSM) and also to visit Langley before returning home, the overall trip being planned to take three weeks.

This was my first visit to the USA, and the first 48 hours were traumatically educating. It started on the Pan American Stratocruiser with a sociable party in the lounge bar downstairs. When this closed at the appointed hour I emerged upstairs to the dimly lit cabin incapable of finding my seat. The privileged and knowledgeable had booked bunks, made by lowering what are now overhead luggage lockers, so spare seats were available. A very professional stewardess weighed up the situation, moved an armrest, got a blanket and tucked me up in two seats, where I slept contentedly until the aircraft prepared to land at the refuelling stop. Thus was proved the fact that alcohol is twice as effective at 8,000 ft (cabin height) as it is at sea level.

The refuelling stop was interesting. Normally this was made at Gander but on this occasion, due to bad weather, we went to Goose Bay where we burst a tyre. Main spares were held at Gander, and it took hours to find the necessary bits from local resources and to restore the aircraft. In the middle of the night we sat in the shack lounge and watched incredulously at the hundreds of assorted people who came and went as their aircraft refuelled. This was at the peak of the post-war European emigration. Today almost nobody has to stop here.

Finally we were airborne again. I was under the impression that, having crossed the Atlantic, we were nearly there. Instead we spent hours flying down the Canadian arctic coast, across the vast expanse of the St Lawrence estuary

and finally along the New England coast where we could see the misnamed freeways jammed solid with commuters. Eventually we did land at New York, where, having experienced the — in those days, hostile — checks of the immigration and customs officials, we emerged into the onset of a sweltering and humid heat wave.

We made our way to our hotel and promptly left for elsewhere to find a cheap breakfast, walked up Fifth Avenue getting a feel for the new environment, and then after a trip up the Empire State Building took the fascinating Circle Line cruise round the Isle of Manhattan. It was by now evening American time (UK minus 5 hours), and we were exhausted by travel and heat. Despite this, wishing to obtain the maximum experience of the American way of life, we booked on Broadway for an Arthur Miller play. This proved to be quite incomprehensible to us, and I have to confess that in the first act I fell asleep. Outside the theatre in the interval for a quiet smoke, we were spoken to by the people who were sitting next to us, and we were comforted to learn that the play was also incomprehensible to them, and that they almost envied me my slumbers.

During this and subsequent days I quickly learned the differences between our respective languages such as: presently means now; pavement means roadway; sidewalk means pavement; vest means waistcoat; singlet means vest; pants means trousers; trunks means pants, etc. I was particularly taken with the signs to the public toilets: not Rest Rooms, as is now virtually universal, but by the then alternative sign of Comfort Station.

The acclimatization and sightseeing stopover in New York completed, Harry set off for San Francisco and I for Washington, both of us worrying as to how our restricted currency was going to last out. Fortunately subsequent experience proved that New York was about twice as expensive as anywhere else that we visited.

When I arrived, Washington DC was at the height of the cherry-blossom season, and what a sight it was! I was fortunate; when the three of us arrived there on the return journey, some ten days later, there was no sign of it. Business there was soon completed and I was in transit for Los Angeles. This was not before I had learned the hard way of another aspect of the American way of life: if your booked room at a hotel has not been prepaid, there is a good chance that it will have been let by the time that your arrive. This was my situation on arriving at the Sheraton Hotel in an overcrowded and booked-solid Washington, and the hard-pressed front desk did not want to know me. Because I was stranded and disoriented I kicked up a significant fuss, such that the duty manager, Mr J. D. Tristani, arrived and with his good offices room was eventually found for me. With this unhappy experience I thought that I had taken the action to prevent it happening to the three of us on the return trip. This was successful when we arrived from Los Angeles, but when we returned to the Sheraton after the night stay in Newport News after our visit to Langley, sure enough there were no rooms for us. Now wise to the system, I sent for Mr Tristani. He greeted me like an old friend, and we were fixed up in the bridal suite, with Harry and me in the bedroom, Barry with a bed in the lounge, with the bathroom in between.

At Los Angeles I had my first experience of the grand American symposium/conference. Lectures galore, many of them concurrent, workshops, formal lunches and banquets, together with organized outings, all conducted in a spirit

of bonhomie unique to the Americans. We even added the standard tour of Hollywood and the Beverly Hills residences, and also made a private visit to the then-unique Marineland on the Pacific coast with its whale and dolphins.

The conference over, a series of discussions with Benson-Lehner began. From these and Harry's discussions in San Francisco we drew up a list of the equipment which we wanted, and cabled Farnborough for their approval. The reply came back 'not approved', as the list differed from that discussed with them before we went out. We petulantly replied that, if that was their view, why had we come out? That had the desired effect, and shortly afterwards approval was forthcoming.

Whilst this traffic shuttled across the Atlantic we paid our day visit to Edwards Air Force Base. We set off by car in the very early morning and drove the 120 miles, stopping off at Lancaster on the edge of the desert for a snack, where an optimistic 'real estate' agent did his best to sell us a 'ranch'. We then continued along the road into the desert but eventually, deciding that we were lost, we pulled up at an isolated building to make enquiries. This turned out to be the base's paint store; it was in a forbidden area, and we were regarded as the enemy who had somehow penetrated the defences. In the end all was sorted out, and we were escorted to our true destination.

In those days accommodation was in wooden huts, even with the most sophisticated equipment in use, and we experienced the debilitating heat and the loneliness which limited many a technician's stay there to three weeks at a time. Of course, conditions there today are very different.

Back in Los Angeles we had concluding discussions with Benson-Lehner on Saturday morning. Bernard Benson was an expatriate British technician who was famed for his hospitality to visiting Brits. Our visit coincided with the annual conference of Benson-Lehner staff distributed on a worldwide basis, at the conclusion of which he always threw a monumental party at his beachside home at Malibu. This was to be the source of our hospitality, and what a party it was! In the afternoon volleyball on the beach, a table-tennis tournament and other diversions; in the evening a Mexican dinner and entertainment, with copious lubrication throughout. With previous experience to go on, Mrs Benson retired to bed before the evening began. At some unmentionable hour we emerged in a state of alcoholic confusion. Somehow, Barry Laight and I between us found the route back to the Statler and bed. When I awoke late that day Harry, who had gone missing, was sound asleep in bed and on the floor lay the inert form of his expatriate friend with whom he had been driving back. It transpired that they had got onto a reciprocal on the freeway, and had been part of the way to San Diego before turning back!

Monday lunchtime saw us on a DC-7 bound for Washington. At 25,000 ft, with lunch just cleared away, a warning of severe turbulence in cumulo-nimbus clouds was given. I was surprised to see the main undercarriage come down. This was to allow speed to be much reduced and hence limit the effects of the turbulence without running into speed stability problems, similar to the opening of airbrakes to reduce minimum-drag speed, as discussed earlier. I had no idea that airline pilots were so technically knowledgeable. Later I found, of course, this was standard DC-7 procedure.

Washington was unbearable, with temperatures in the 90s and humidity 98 per cent. We were glad when the time came to drive through the beautiful

countryside of Virginia, passing through Richmond and Williamsburg to spend the night in Newport News with views across the estuary to the huge naval base at Norfolk. We spent a day at Langley, seeing for ourselves what had been arranged, and then drove back up to Washington for a wash-up meeting with all interested parties. This went off satisfactorily, with the task completed in two weeks instead of the scheduled three.

We went off to a celebratory lunch at a favourite restaurant of the BJSM staff, located somewhere near the Dupont Circle and with the proprietress known to the BJSM officers as Auntie. In high spirits we were given the private back room in which to enjoy ourselves. Studying the menu I dissolved into gales of laughter. Auntie asked me what it was all about, to which I replied that I had just seen the best possible epitaph for American food — one item was 'smothered in tomato ketchup'. After that, home and back to normality.

Although out of sequence, I made two subsequent US trips which are worthy of comment. On a Thursday morning I was due to attend a Management Board meeting at Kingston, and then to host a social evening at RAF Honington on the Saturday. At very little notice I was required to attend a conference in Washington on the Friday. Leaving the Board meeting before it had finished, I caught the last flight of the day to Washington, and arrived back on the 'red eye special' on the Saturday morning. Transport took me across to Thetford, where we duly formed up the total party from Brough and began a hectic party into the small hours at Honington. I now know what the cube of normal jet lag feels like.

The other occasion was in 1967, in company with John Stamper. The itinerary involved New York, Seattle, Los Angeles, Anaheim, Dallas and St Louis, which was a near-circumnavigation of the United States. In the course of this, two sociological things were brought home to me. Despite the vast modern complex of Seattle, it was barely a century since the first white man had settled there. Secondly, in the various individual areas of the country which we visited there was a concentration of names of a particular European country, and one then realised the problems there must be in creating this mixture into a single nation in such a short time. I could also appreciate the reasons for their enthusiasm for the history of other nations, and the acquisition of their artefacts.

Seattle was hosting an Anglo-American aeronautical conference which included fascinating visits to the various Boeing sites. The mock-up of the projected 747 was on view, and the prototype 737 was in one of the hangars. I wondered how the latter could compete with the One-Eleven and DC-9, and wasn't it asking for trouble with the intakes so close to the ground? How wrong can one be? The 300 ft-long mock-up of the 2707 supersonic transport was shown as a prize exhibit, but John and I could not believe in it, and this time at least we were right.

Our stay in Seattle included the first day of the bear-shooting season in the hills. We were told that any madman with a gun participated, and that more humans than bears would be shot, the relative score being given at frequent intervals on the radio. We found this difficult to believe, but sure enough it was true.

On the social side, the beautiful scenery was much enjoyed, but as this was the height of the brain-drain era we were inundated with visits from our expatriate friends. Whilst these were very enjoyable, the joy was tempered when, having been kept up until the small hours of the morning, one had to be up again at 5.30

or so in order to catch the early flight. This regime was continued at both Los Angeles and Anaheim, and we must both have had the constitution of an ox to survive.

Visits to the various aircraft firms invariably involved a demonstration of their recently constructed simulator, of which they were always very proud. Whilst at Anaheim we were hosted for an evening at the nearby Disneyland. Unfortunately, this immediately followed an exhausting day trip to Edwards Air Force Base, which had necessitated a 6.00 am start which itself had followed one of those heavy evenings with some brain-drainees. After sampling some of the delights of Disneyland, John and I sank into the comforts of a restaurant. It happened to be set in the middle of a jungle with appropriate actions and sounds coming through the glass sides. After a while John turned to me and said, 'You know, Roy, this is the greatest simulator of them all'.

We finally completed the circuit and I introduced John to McDonnells at St Louis and we caught the plane home after a very educational three weeks.

Chapter 7
The Buccaneer — a Brief Description

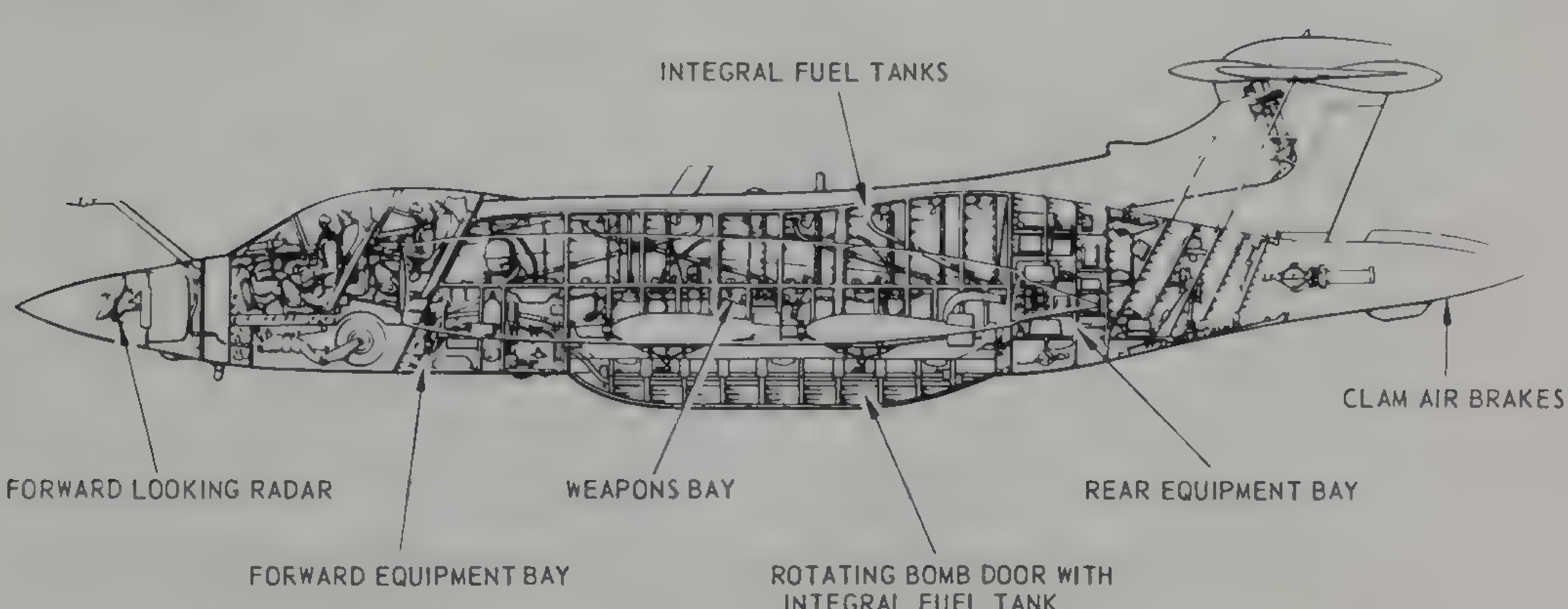
Before embarking on a record of the development programme of the Buccaneer, for completeness I must outline the essentials of the design.

The fuselage is of fairly conventional skin-and-stringer construction, with stretch-formed panels. Two heavy longerons run the length of the centre fuselage to act as closing members for the weapons bay and to react catapulting and arresting loads. The upper centre fuselage is double-skinned, and contains the integral fuel tanks.

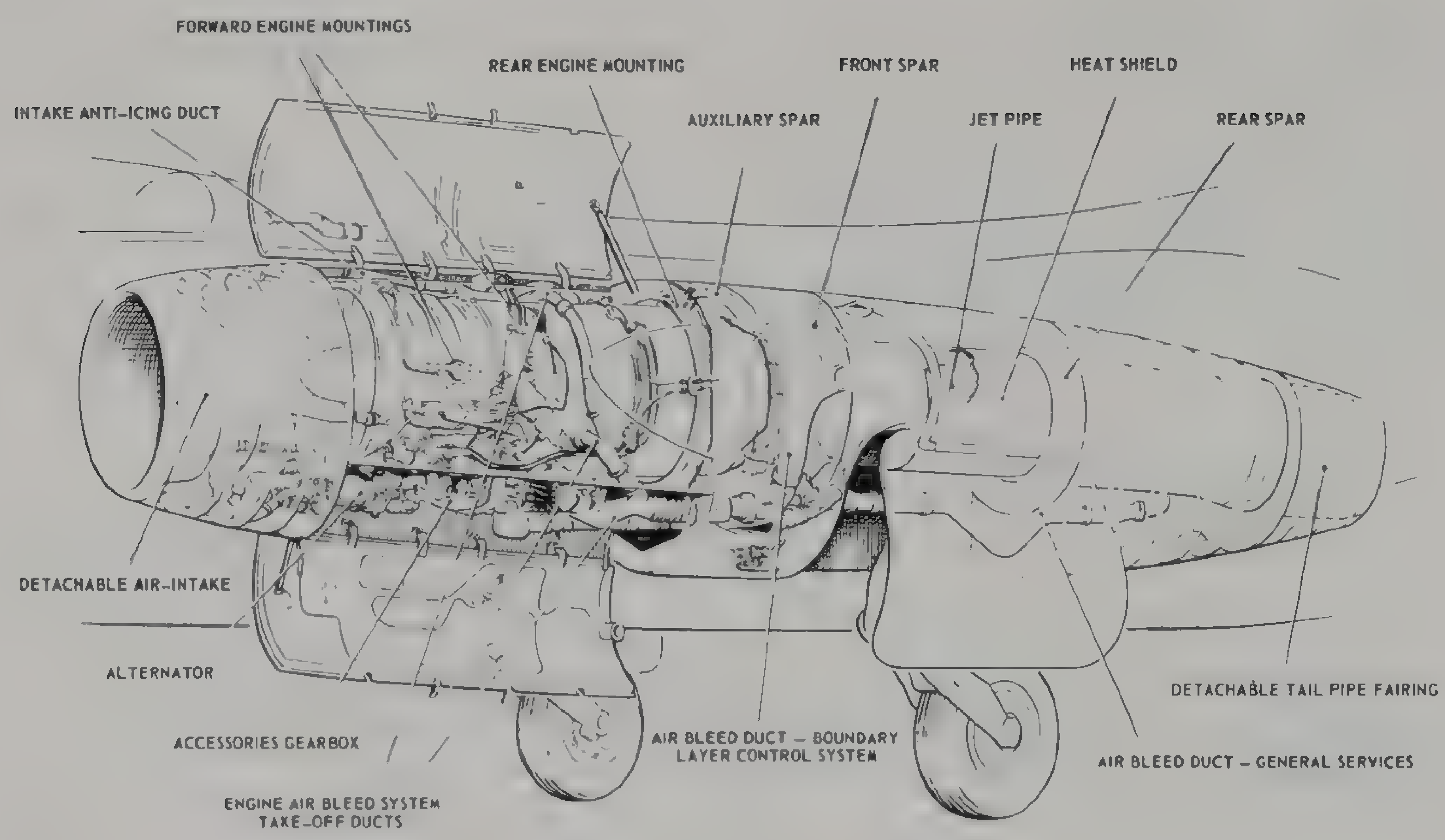
Major equipment is housed in three main areas: the lower forward fuselage, on either side of the nosewheel bay; the lower centre fuselage, between the forward end of the weapons bay and the rear of the cockpit (known as the accessory bay); and the rear fuselage (known as the radio bay). The two latter bays are accessible, via a door in the bottom of the fuselage, to a man standing on the ground.

With the exception of the inner wing, all flying surfaces are of integrally machined skins and ribs. From wing-fold to wing-fold most of the loads are carried by machined steel forgings, with spars in the wing, rings round the jetpipe and attached to spiders which extend across the fuselage and over the weapons bay.

General-services hydraulics, with a pump driven by each engine, operate at 4,000 lb/sq in. The duplicated flying-control systems, each with its own pump,



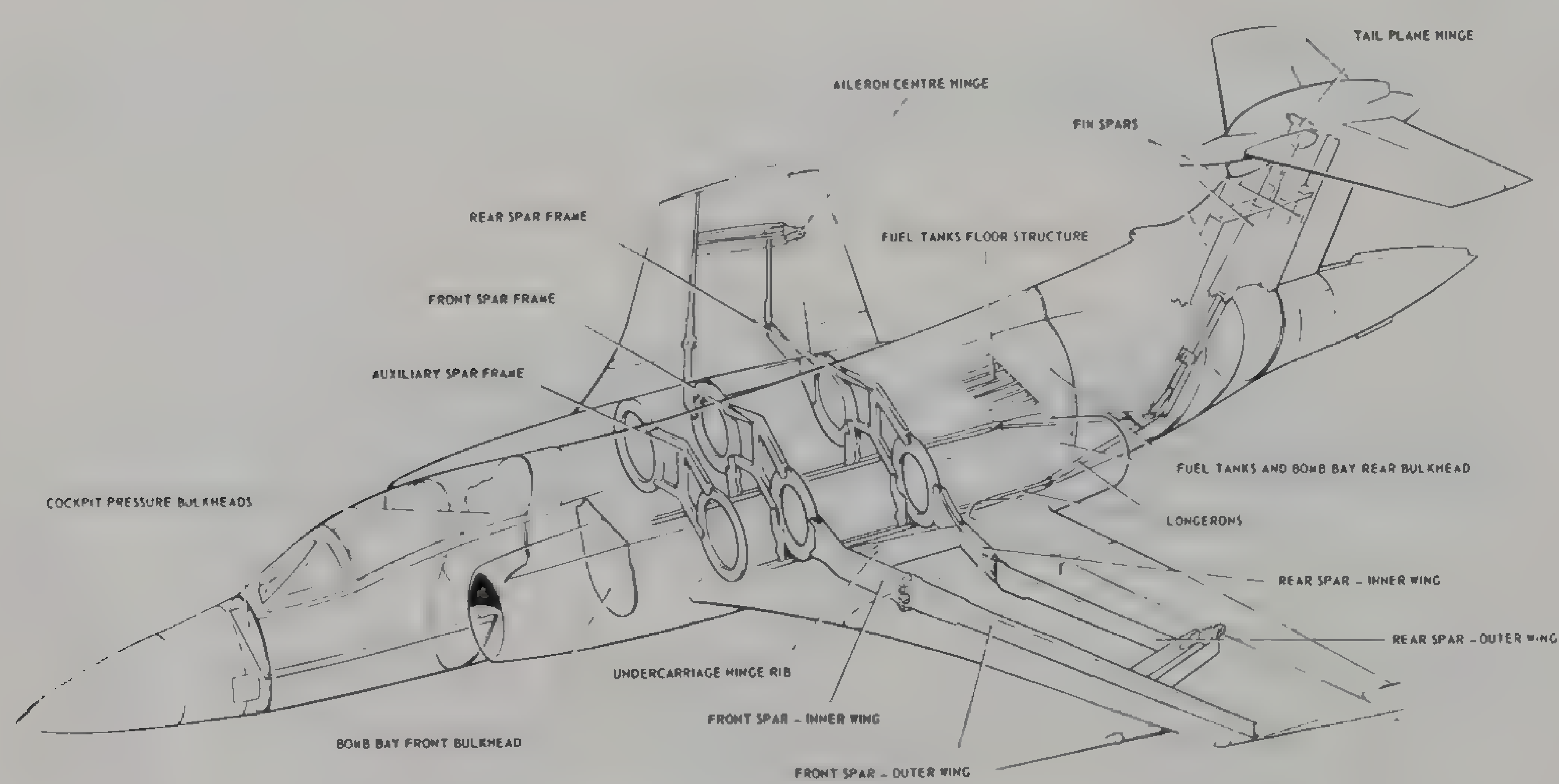
Buccaneer — side view of the fuselage arrangement.



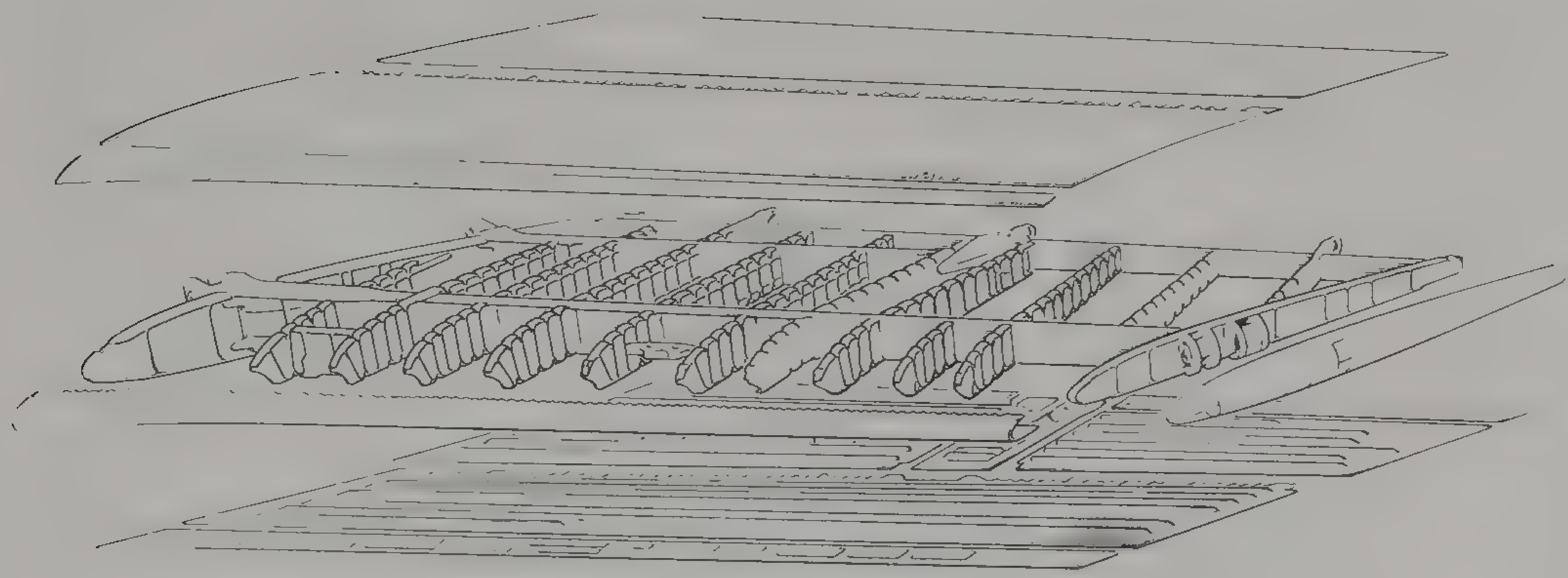
Buccaneer — engine installation.

operate at 3,300 lb/sq in, and there is an emergency cross-connection with a pressure-reducing valve from the general-services to the flying-control system to cater for multiple failure. It was originally intended to operate the flying controls at 4,000 lb/sq in as well, but a reduced pressure was found to be necessary to obtain the right combination of jack effort and fluid-column stiffness.

The essentials of the boundary-layer control system have already been described. Blowing air for the wing is tapped off the engine manifold by a servo-operated butterfly valve. There is a separate offtake for auxiliaries, from which the air is distributed around the aircraft by a ring main. To avoid duplication of ducting, air for the tailplane boundary-layer control is taken off the ring main via an electrically operated valve. Each engine offtake contains a non-return valve



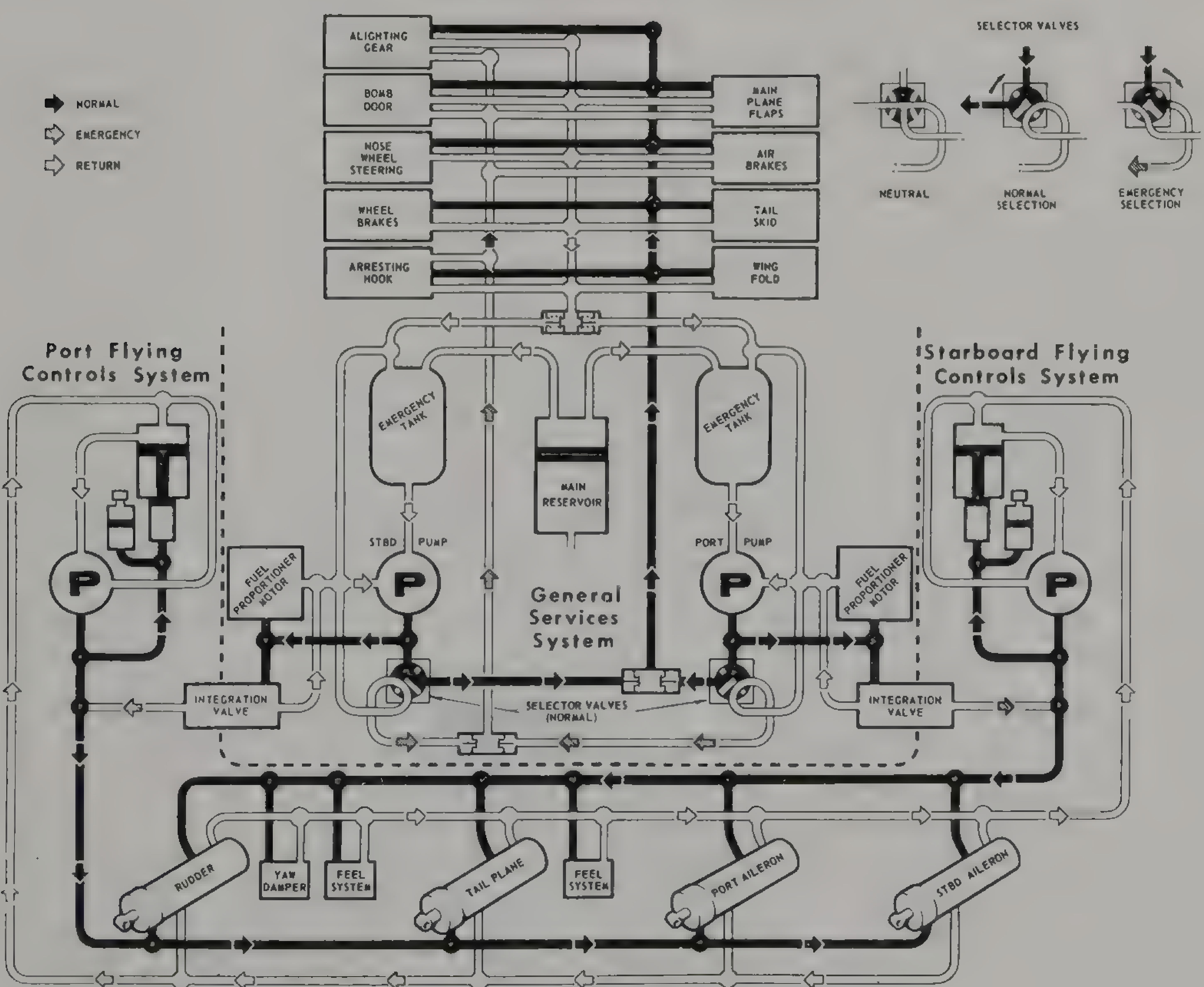
Buccaneer — primary structure.



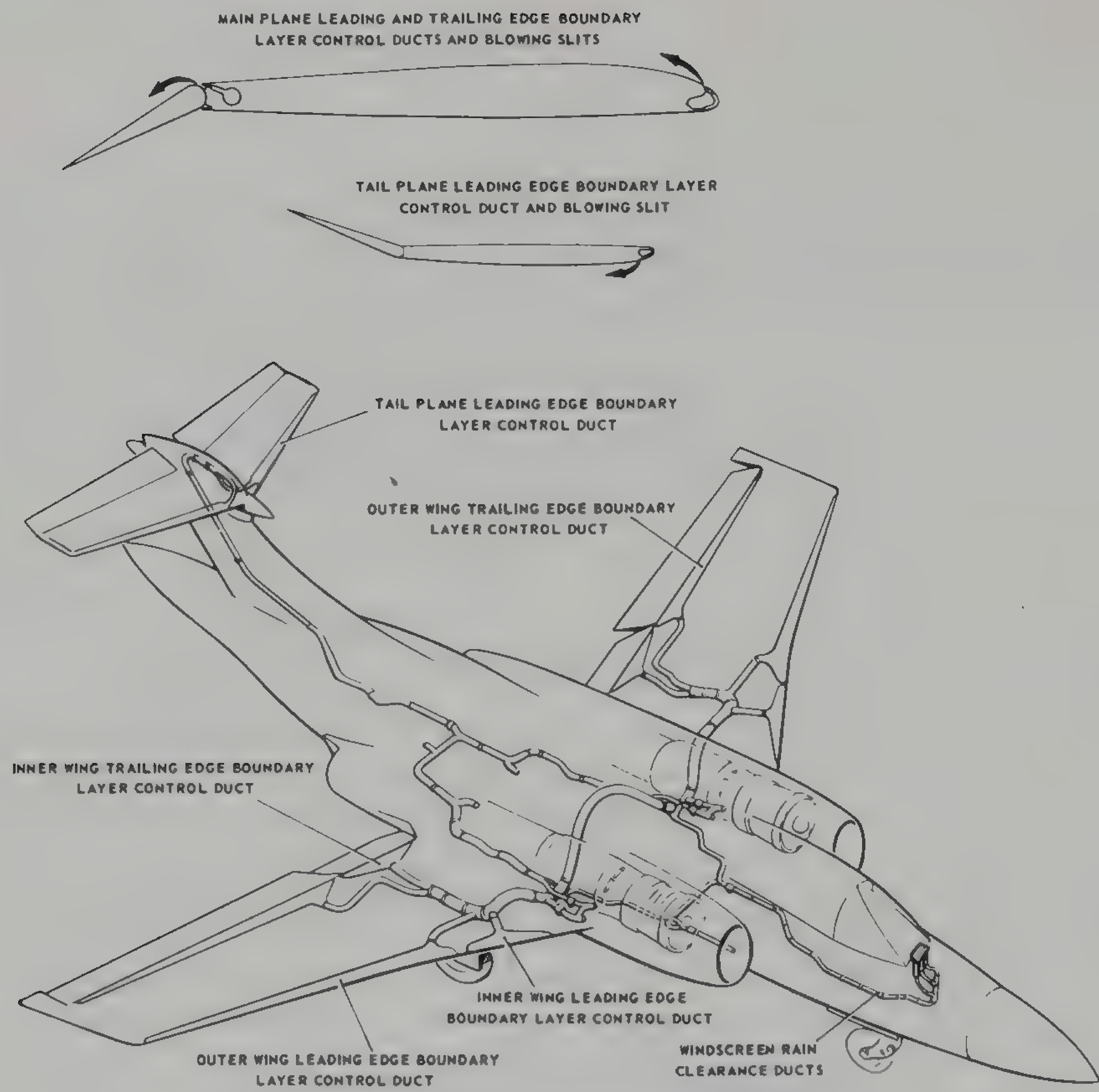
Buccaneer — outer wing.

to prevent malfunction in the asymmetric case. As described later, this had an unfortunate history.

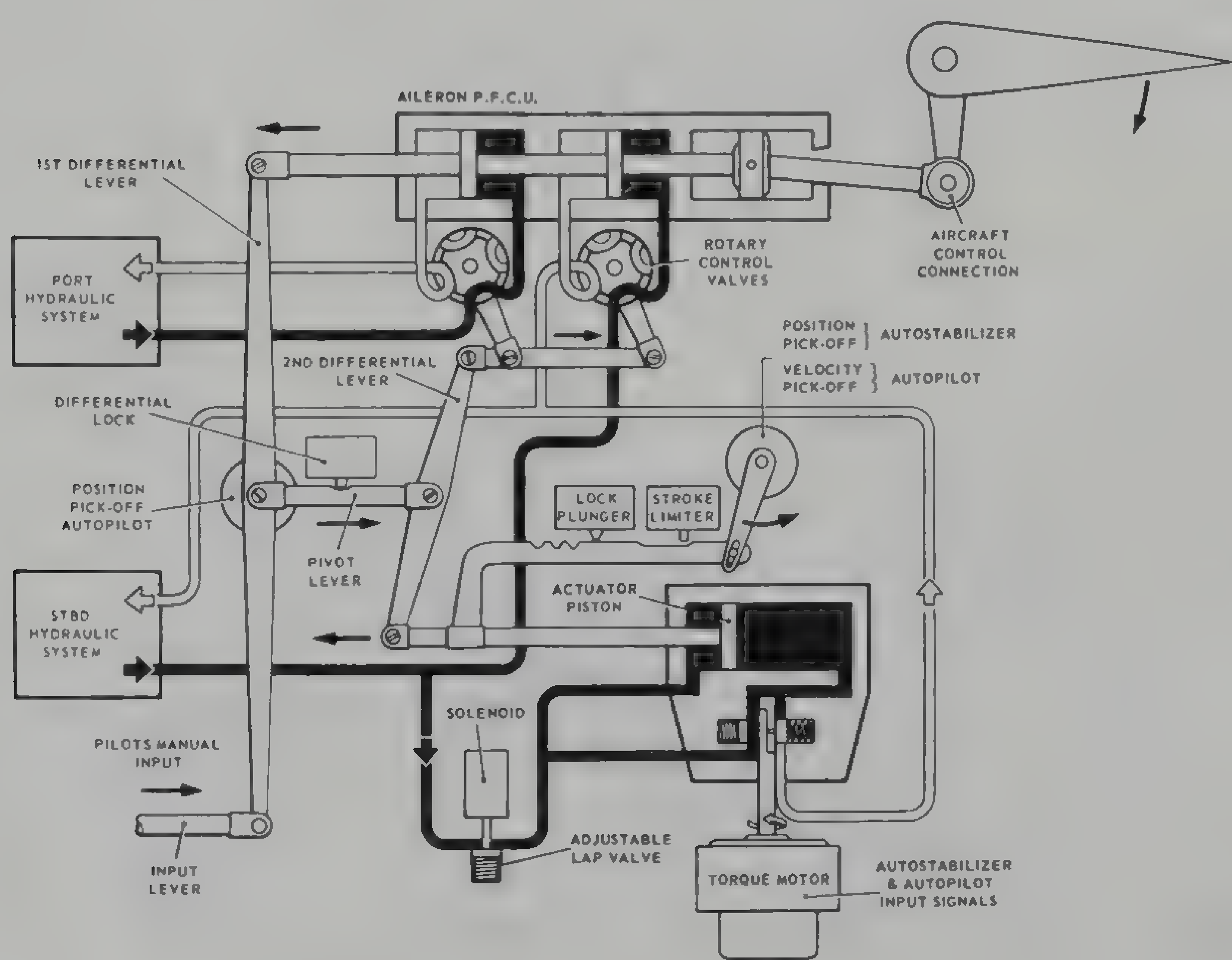
On the Buccaneer Mk 1 constant-frequency AC, essential for much of the avionics was provided by a 10-kVA air-turbine alternator with a standby inverter for essential services. Two 6-kW engine-driven generators provided power for the main airframe services. The air-turbine alternator was a source of constant trouble. With the introduction of the Mk 2, with Spey engines, the whole



Buccaneer — hydraulic system.



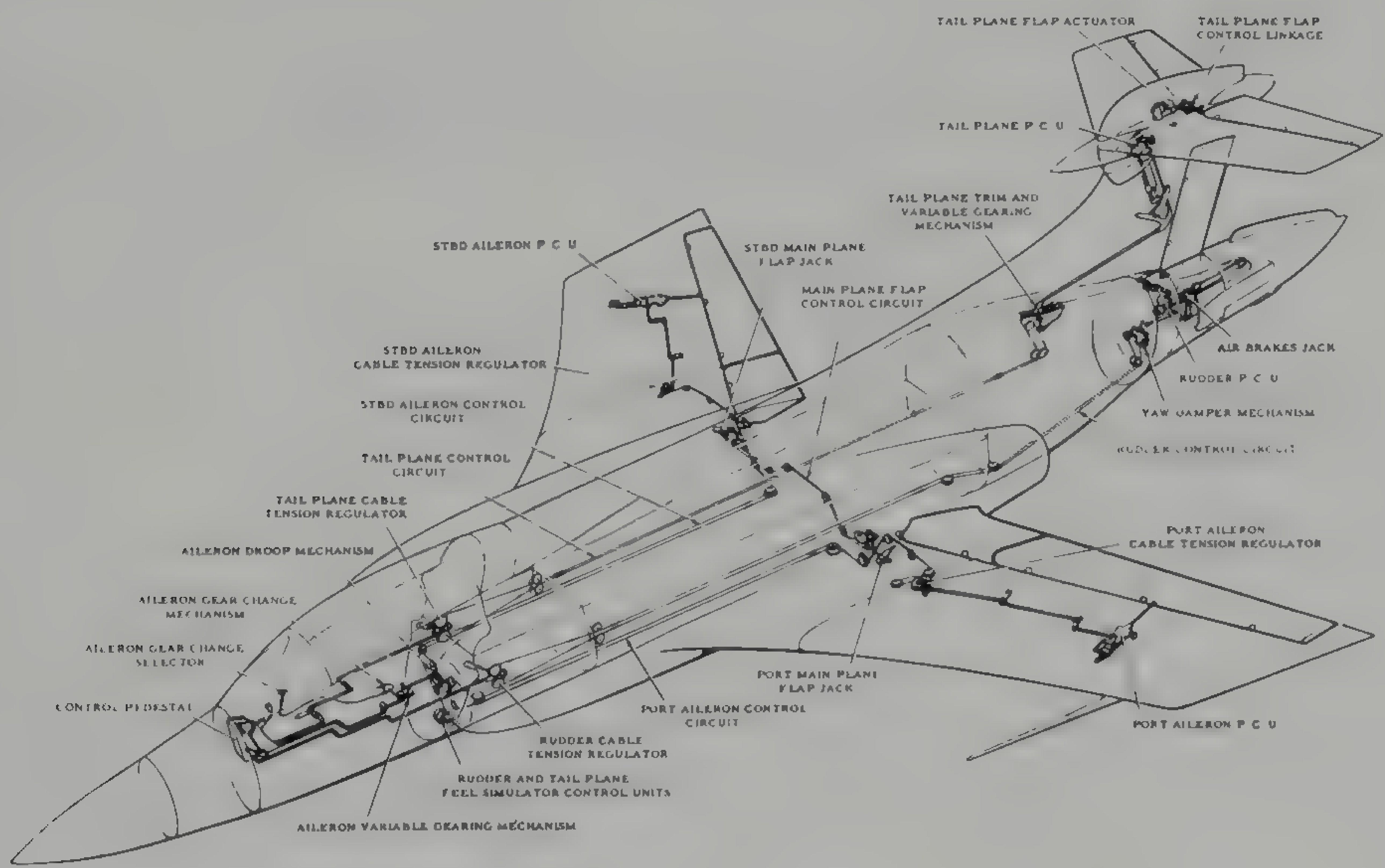
Buccaneer boundary layer control system.



Buccaneer powered flying control unit.

electrical generation system was replaced by two engine-driven 30-kVA constant-speed alternators.

Other features will be described as appropriate in connection with the development programme.



Buccaneer flying controls.

Chapter 8
Buccaneer Mark 1 Development Programme

First Flights at RAE Bedford

With the little airfield at Brough totally unsuited to operation of NA.39 type aircraft, arrangements were made for the lease of the necessary parts of the disused wartime airfield at Holme on Spalding Moor, ten miles from Brough as the crow flies but 18 miles by road. The main 6,000 ft runway, taxi tracks and buildings on the main site for offices and laboratories were refurbished, equipped and brought up to operational status, together with the large J-type hangar. Later in the programme the two adjoining T2 type hangars were added, one for aircraft and the other as a store.

The Ministry required emergency arrester gear to be fitted. Initially this was of the nylon pack type, but eventually this was replaced by the more efficient water-squeeze type. Both were in due course to prove very useful, although on one occasion the arrester hook dropped during the takeoff run, engaged the arrester gear and an astonished pilot was brought to a halt with the engines at full throttle.

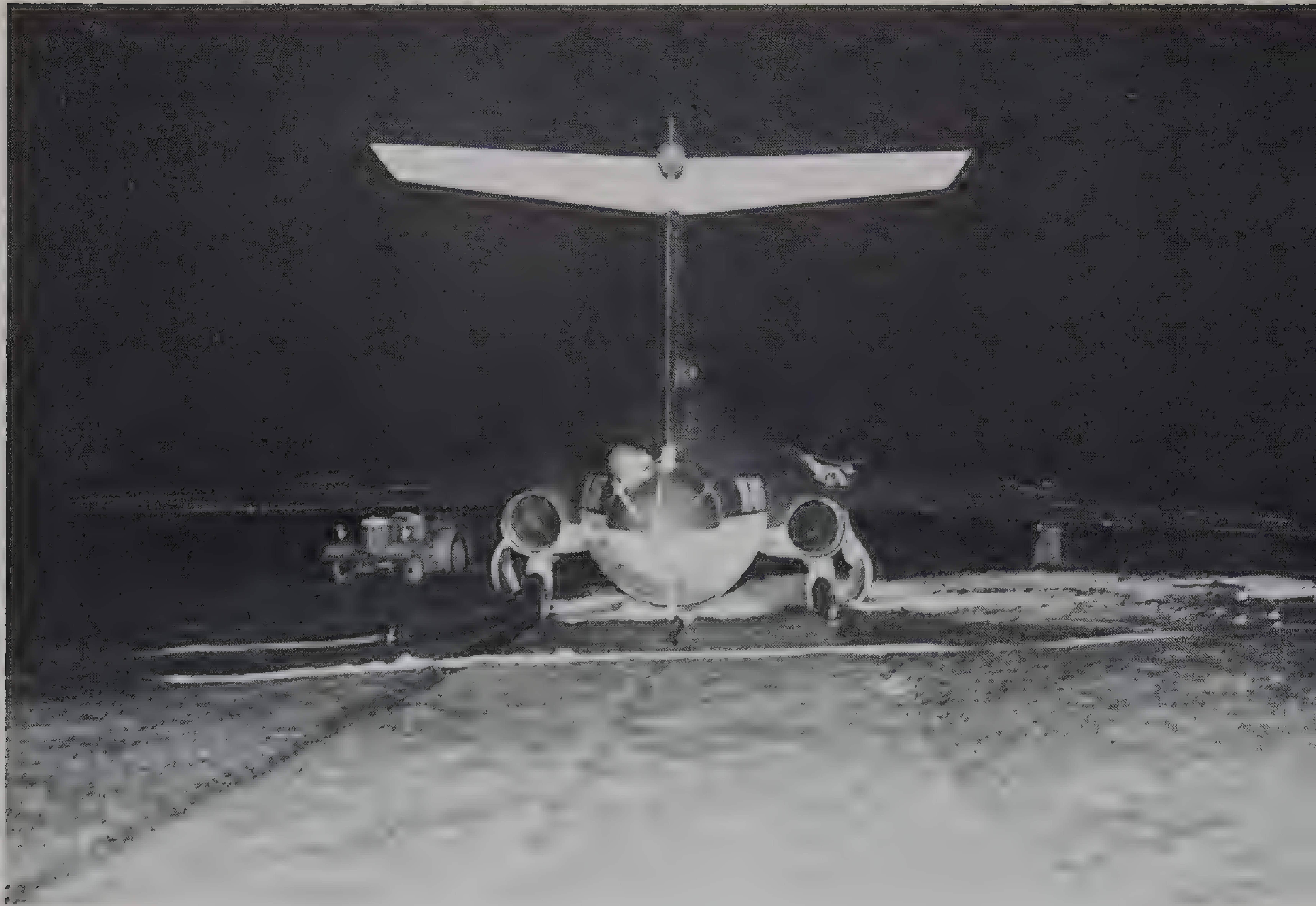
Even with the additional safeguard of the arrester gear, the risk of using Holme on Spalding Moor for the initial flights was ruled to be too great, and one of the major test airfields was to be used. Given the choice between Boscombe Down and RAE Bedford, the latter was chosen on account of its greater proximity to Brough.

With an originally specified date of April 1958 for the first flight, design, build and testing proceeded apace, and March 1958 saw resonance testing and initial engine runs complete. The first aircraft, XK 486, was then dismantled and transported to Bedford by road, under a shroud to hide its identity. It was painted smartly in blue and white.

Early April saw everything ready for first flight, in preparation for which high-speed taxi runs were planned. This was when problems with the engine, which were to plague us throughout the programme, struck us in a most unexpected way. To reach the far end of the Bedford runway, the aircraft had to taxi some two miles, some of which was downhill. Because of handling problems, idling rpm, and hence thrust, had been set higher than planned. The result was that frequent application of brakes was necessary during the long taxi run. Having arrived at the runway, Derek Whitehead lined the aircraft up, accelerated to about 100 knots and then applied full braking. Before the aircraft had come to

Initial engine runs on the Mk. 1 Buccaneer at Brough, February 1958. *(BAL 11273)*

XK 486 shrouded in transit from Brough to Bedford on 11 April 1958. *(BAL 11537)*



XK 486 stranded on the grass at Bedford after a taxi run during which the tyre burst. Note the damage to the starboard inner wing, 21 April 1958. *(BAL 11561)*

XK 486 taxis in after first flight, 30 April 1958. *(BAL 16606)*

rest, the brakes spectacularly caught fire, and the aircraft was steered on to the grass. With the aircraft now stationary, one of the high-pressure tyres burst, fusible plugs not at this stage being fitted. Assisted by Murphy's law, the direction of the burst was directly upwards into the wheel bay, causing serious damage to the inner wing, for which a reasonable repair time would be three months. By some miracle a works team had it ready by late April, and we were ready to go again.

In the meantime, in an office borrowed from the RAE, I got down to some serious sums on braking energy and associated temperatures. Before attempting a first flight we did a series of taxi runs up to various speeds, with estimated acceleration and stopping distances staked out and final brake temperatures measured by Dunlop using a probe. As a result, we had a good correlation which was to prove useful over the years. It was of interest to discover that on the ill-fated first high-speed taxi run, by the time that the aircraft lined up at the end of the runway, thanks in part to the unduly high idling thrust, energy equivalent to a normal landing had already been put into the brakes.

Dead on schedule, 30 April 1958 saw XK 486 make its first flight, with no problems. Takeoff and landing were to be unblown and, whilst it was not on the test schedule, I suggested to Derek Whitehead that he might care to try the airbrakes, as I though that the use of them on landing could be helpful. This he did, but without warning the chase Meteor, which promptly overshot into the distance.

The following flights concentrated on investigating the blown high-lift configurations. Results on the whole were very satisfactory, although with ailerons drooped 30° there was excessive adverse yaw and some buffeting. However, reducing the droop angle to 25° caused no loss of lift and gave satisfactory handling. The pilots — Whitehead and G. R. I. 'Sailor' Parker — deserve praise for the way in which they coped with these tests. To give flexibility in experimenting, flap and aileron droop were selected separately, and the tailpane flap, which also involved a separate selection, came out to full travel. If selection was not made at the right time this could cause some interesting manoeuvres. Eventually, a completely integrated system was fitted to the eighth aircraft onwards.

The spell at Bedford lasted longer than we wished — three months — as it took time to convince the authorities concerning the move to Holme on Spalding Moor. The aircraft was restricted to 350 knots over this period, and while this was quite compatible with the original aims of the Bedford programme, as time went on it became increasingly frustrating. The overriding reason for this limitation was the requirement to do a canopy jettison test under full flight load, and the only place that this could be done at this time was on the aircraft itself, at Holme on Spalding Moor.

By and large, the Bedford flying went very well, and two other pilots were converted to type. The second flight, however, brought quite a scare. On entering the circuit the nosewheel would not come down and, despite all emergency selections and bunting of the aircraft, it stayed up. The decision was made to do a nosewheel-up landing, and hope for the best in terms of resultant damage. As we watched the aircraft turn in, the airbrakes were opened, and to our astonishment and delight down came the nosewheel. The subsequent investigation was not without interest. Operation of the airbrakes used so much

An array of six development aircraft at Holme on Spalding Moor, August 1960. Left to right: XK 488, 487, 523, 489, 524 and 525. *(BAL 15505)*

XK 523 making a 'touch and go' on HMS *Victorious* prior to making its first deck landing, January 1960. *(BAL 14553)*

XN 935 with the bomb door open, November 1962. *(BAL 19081)*

The Buccaneer assembly line in B Shed, seen over the wing of a Beverley, January 1961. *(BAL 16353)*

hydraulic power that there was a momentary drop in the pressure in the rest of the hydraulic system. Nosewheel steering was via the rudder pedals, provided an electrical circuit was selected. A flag engaging with a fork fitting gave a mechanical link with the steering mechanism with the nosewheel extended, but on retraction it was disengaged. At least it was supposed to be, but it was possible to assemble it in such a way that it was left partially engaged, and this was the situation which had arisen. Rudder-pedal movement during the flight had caused the nosewheel to slew in its bay, and it had then jammed against the bay sill. As the airbrakes opened, pressure in the steering mechanism fell, allowing the nosewheel to centre and thus be free to come down. On such slender threads of luck do even the most carefully planned programmes depend for success. Needless to say, some rapid modification action followed this incident.

First Phase Trials at Holme on Spalding Moor

July 1958 at last saw XK 486 at Holme on Spalding Moor, with an outstanding works programme and the canopy jettison test to be done. A metal canopy was made and fitted, and connected to a jack which was attached at the other end to the hangar roof. Catch nets were erected, but we were still apprehensive that the behaviour of the released canopy was unpredictable, and that our one-and-only NA.39 could be damaged. The sears of the canopy jettison guns were operated by a string led outside the aircraft. The tension in the hangar was considerable — but so, apparently, was that in the string for, as the final countdown was made, the string broke. Fortunately, the next attempt was successful in every way.

Back on the flight-line the flight envelope leaped to 450 knots, ready for the SBAC Show at Farnborough, although for security reasons the aircraft was based at Boscombe Down during the show. Soon afterwards, in October, 486 went to Boscombe for a first preview which was, in the main, successful. The first day of the preview was dead calm and, with the relief of their first flight behind them, the pilots were happy. The following days were very turbulent and, as the autostabilization systems were yet to be fitted, they found the aircraft quite a handful to land. Also, as these pilots were mainly flying Scimitars and Sea Vixens, it was no surprise for them to consider the NA.39 to be underpowered.

By September XK 487, with its straingauges and flutter exciters and instrumentation, was active in the programme, and vital to the extension of the flight envelope. This it did efficiently over a period, with only one hiccup, where we discovered reducing tailplane damping which could have led to flutter. An internal balance weight was fitted to each tip of the tailplane, which removed the problem.

The use of straingauge testing was vindicated, when results showed that, while little trim change was coming from the airbrakes, a lift load was being induced on the airbrakes themselves but developing an equal and opposite load on the tailplane. Each quite severe load had to be reacted through the respective structures.

The tailplane jack straingauge was also used in another context. Testing through the Mach 1 range was bedevilled by uncertainty of the accuracy of the airspeed and Mach instruments. The technique used was to go to a high altitude,

enter a dive and pull out when a certain straingauge reading came up. Aided by sonic bang on the airfield and other readings, we rapidly built up a transonic calibration. This programme, however, got off to a false start when, having taken off for the first of this series of flights, the aircraft immediately landed reporting that the maximum reading to be allowed had come up as they took off. As the one who had designed the tailplane hinge position to give equal loads in the low-speed high-lift and the high-speed conditions, I should have remembered! It took someone else to realize this fact, and send the aircraft on its way again.

At this stage the flight-development organization at Holme on Spalding Moor was somewhat fragmented. The traditional flight-test department, fresh from its role in the development of the Beverley, reported to Bert Smith and to me. We had overseen the preparations for the flight testing the NA.39. Barry Laight, in his wisdom, had seen fit to detach senior designers from each discipline as a flight-development support team, and a very good concept it turned out to be. This new group reported to John Stamper, also newly appointed to oversee their activities. He had no direct control of the flight-test department, although in practice, with the internal politics as they were, they operated more as a service than as a controlling department.

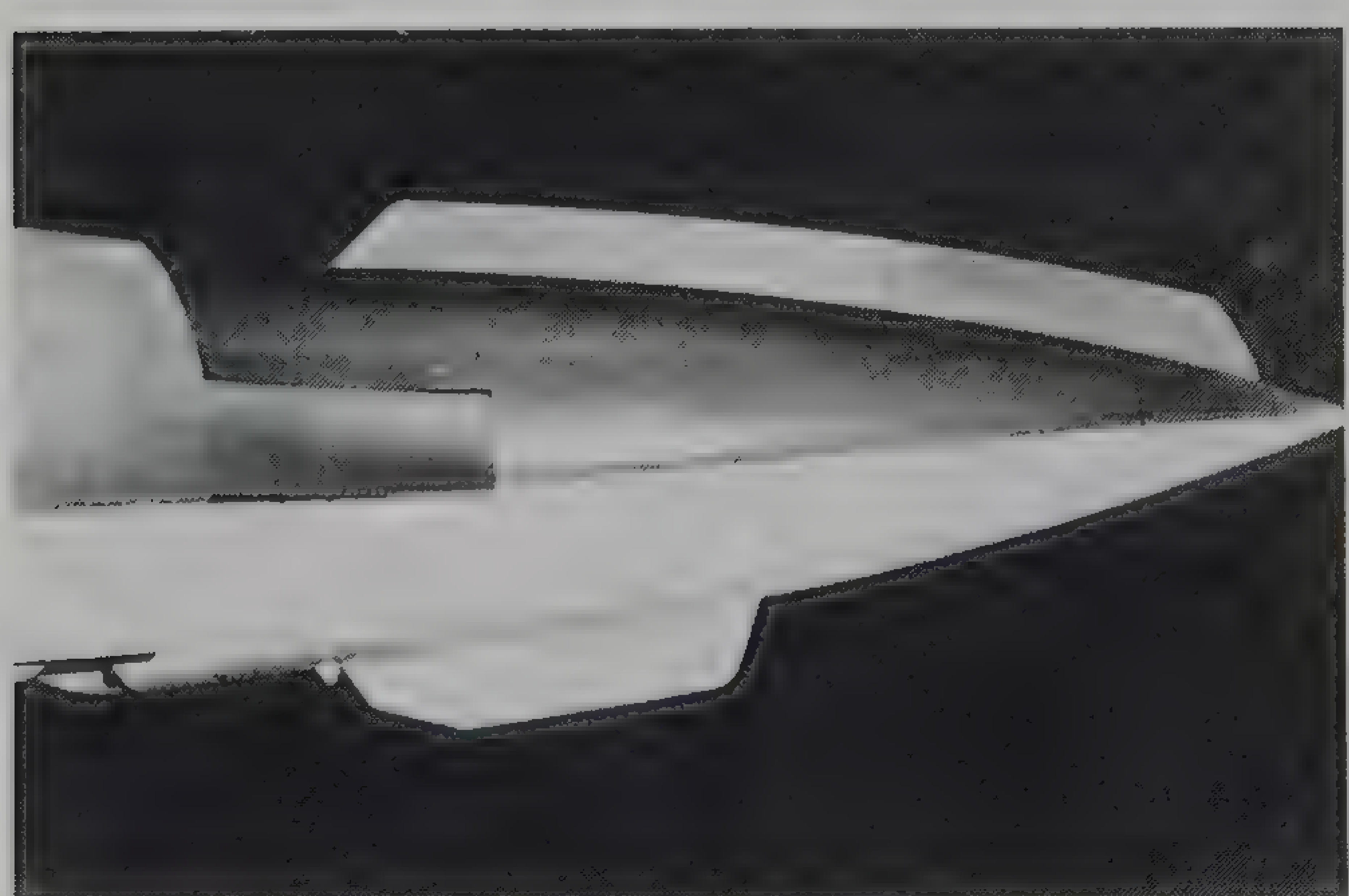
Early in the programme, and having myself drawn up the master programme, I drew Barry Laight's attention to shortfalls in longer-term engineering actions which were essential if the programme was to be sustained. The result was that, there and then, I was relieved of all of my other duties except for some limited future-project activities, and posted out to Holme on Spalding Moor to be responsible to Barry Laight for the long-term flight development programme. At this stage I had no staff and no executive power over either of the other two factions — who were, to some extent, battling it out between them. Neither exactly welcomed my appearance, in this new role. Life was not easy.

An amusing incident occurred which embraced the inter-group rivalry in its very early days. As related, the initial emergency arrester gear fitted on the airfield was of nylon packs buried below ground level on either side of the runway, with the arrester wire stretched between them. The engineering section wished to establish the break-out load of the shackle connecting the wire to the nylon packs. The best way to do this was to run an aircraft, with its hook lowered, into the wire at a predetermined speed, the shackles being firmly earthed and not connected to the nylon packs. The flight-test people, purely on a gut feeling rather than specific grounds, objected. They said that it did not justify any risk to a precious aircraft, and that there must be other ways of undertaking the task. The engineers stated that all contingencies had been considered, and that no risk to the aircraft existed. The flight-test objections were overruled, and one afternoon saw 487 charging down the runway with arrester hook lowered to engage with the wire at the desired speed. As calculated, the shackle pins broke; but then the unplanned contingency came into play. Some think that, with the aircraft continuing forwards with the wire still in the hook, the two shackles met and bounced off one another. What is certain is that, as the pilot applied the wheelbrakes, the shackles and wire continued forwards and up both jetpipes, to cause expensive damage.

This left both sides rather unhappy at the outcome, but with the flight-test people claiming a slight moral victory. Happy to relate, as the tempo of the work

in hand increased, we all got together to form ourselves into a homogenous organization. When we presented it to him, it met with Barry Laight's approval, and it worked very well for the rest of the programme.

Flutter testing with the instrumentation available, particularly for high speed at low level, required the calmest air possible. This would normally be obtained just after sunrise or before sunset. The situation started to arise in early summer, when other activities had been completed by 6.00 pm; then we would have to wait until 9.00 pm to fly 487. Nothing was more natural than to go down the road to take up residence in the lounge bar of the Red Lion. This, I regret to say, became a regular feature of life, for up to say 8.30 pm the bar was devoid of other customers, and we had found an alternative conference room. The landlord, Harry Engel, was most co-operative. He would disappear, to leave us in private for any discussions we might start, and we even became proficient in pulling a pint from the wrong side of the counter. Of course after 8.00 to 8.30 pm, with other customers arriving, the evening became entirely social. It was through this that I learned a basic rule of pub time: that from 6.00 pm until 8.00 pm is two hours, but from 8.00 pm until 10.00 pm, which in those days was closing time, is ten minutes.



Final standard

Buccaneer airbrakes.

Whilst these sessions were poison to domestic bliss, they did a great deal to increase the *espirit de corps*, and more than a little to help the job along. There should be a red lion in the crest of every Buccaneer squadron.

Returning to the actual programme, throughout the winter of 1958-59 XK 486 and 487 explored the complete flight envelope. The aircraft performed roughly as expected, except for three areas which required more detailed work: variation of trim over the full speed range due to airbrakes; flying control and autostability gearings to cover all critical cases; and engine performance and handling.

This period also saw the emergence of XK 488 which, after clearance trials, was to be handed over to de Havilland Engines, and also XK 489 with its navalization and stores-carriage features.

For three months of midwinter, fog and generally filthy weather precluded any flying, but the time was not entirely wasted by bringing the aircraft up to an improved standard. Conditions in the unheated hangar were severe, but by the time the fine weather arrived we had managed to make a box of a quarter of the hangar and heat it. Much later, heating for the whole hangar was installed.

At first the airbrakes were fitted with radial strakes, in accordance with recommendations from the RAE. We had checked this out in the Brough wind tunnel. As trials progressed, and the flight envelope was extended, the configuration proved to be unsatisfactory. the combination of transient conditions and the influence of engine efflux resulted in the tunnel being an unsuitable tool for this problem, and the only recourse had to be an ad hoc flight programme. A range of strake configurations was tested in this way. It proved to be a more arduous task than expected. Not only had trim change between varied end conditons to be minimized, but some reversals of trim during airbrake operation had to be eliminated. Finally, a configuration of vertical strakes with different areas at top and bottom emerged as the best compromise. The same period also saw intensive flying on buffet boundaries, and the development of a vortex-generator configuration.

Development of the Flying Controls

The primary flying controls were introduced as self-centring, with simple spring feel, but with non-linear gearing on both tailplane and aileron circuits. They were soon found to be excessively 'lumpy', and to require an undesirably high break-out force. As a result, a major investigation was launched. This included rig testing to bring the mechanical aspects of the circuits up to a standard which we considered to be essential for an aircraft required to fly at high speed at low level. When this was achieved, the new standard was incorporated into all aircraft. With the flight envelope by now extended into the attack operating range, serious flight trials began to optimize the system.

For longitudinal control, tailplane movement was 28°, with stick authority ±7° about any position and stick travel of ±4 in, the remainder of the travel being obtained via the trim switch at a rate of 0.8° per second. Initially the spring feel gave a maximum force of 16.5 lb, but with a break-out force of some 4 lb. The spring box was replaced with one with the spring free at one end. This produced a large improvement, but at the expense of self-centring power. With the other detail improvements in the input circuit, breakout force was reduced to 0.5 lb, and all lumpiness in the control removed.

It was felt in the course of development flying that the simple spring feel could with advantage be improved with a simulated V-feel (proportional to airspeed) to give a more constant stick force per g. A q-feel unit giving 62 lb force at maximum stick deflection at maximum EAS, and 13 lb at 200 knots, was fitted in addition to the spring feel, which was reduced to 9.5 lb.

The non-linear gearing fitted originally, with the ±7° authority, varied by 4:1 at the limits of travel. Carrier trials showed an increase in stick authority to be highly desirable, and this was increased to ±9.5°. With no change to the gearing cam, increased sensitivity was introduced, leaving a question mark about control at high speed at low level. However, autostability gearings were also being studied. A gearing of 0.125° of tailplane rotation per degree per second rate of pitch proved to be right for the high-speed case, and also eased the problem of the change of stick gearing. The opposition to pitch rates imposed by the pilot gave an effective reduction in the stick-to-tailplane gearing over the initial range of stick movement, and just nicely avoided any oversensitivity. Any opposition to coarse stick movement was undetectable, as autostability authority was limited to 0.5° of tailplane.

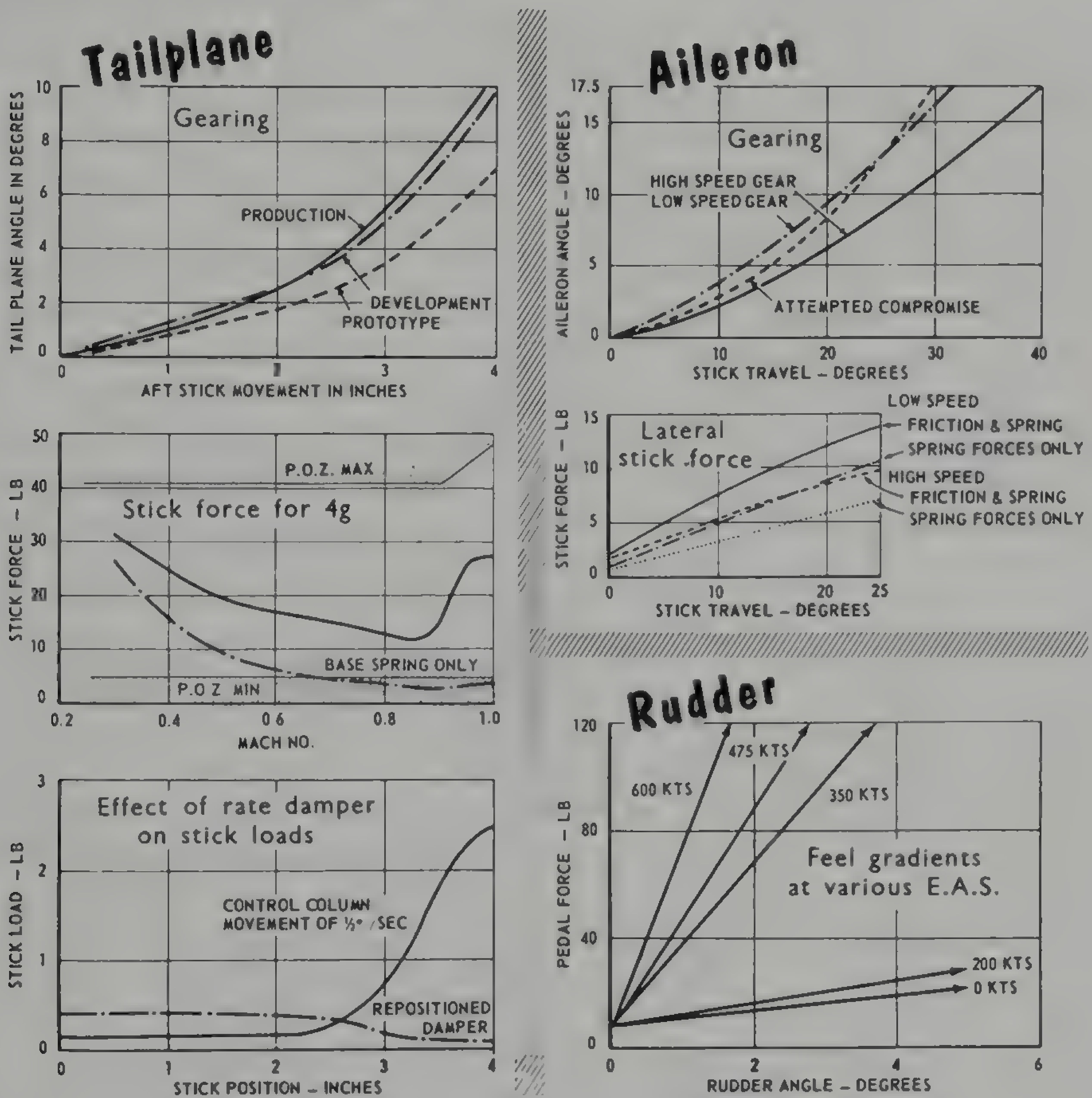
As a result of some handling problems during catapult launching — mainly pilot-induced — a hands-off launch technique was developed which required a more negative tailplane trim setting. A further change was made to give increased positive stick authority to assist any recovery action, which, however unexpected, might at some time be required.

To conclude the story of longitudinal control, during a deliberately over-trimmed launch on a deck trial, the aircraft, XK 529, pitched up, stalled and was lost. Records recovered showed that a very high stick force had been applied, but to no effect. Later in the programme, at Holme on Spalding Moor, the pilots reported lumpiness when coarse stick movements were made at low speed. Static measurements indicated nothing amiss, so it was concluded that the cause had to be dynamic. It was then remembered that a viscous damper to prevent input circuit resonance had been fitted, positioned between the non-linear gear and the powered flying control unit. The effect on moderate stick movements when the gearing was low was minimal but, as stick travel increased, its effects were magnified considerably. With back stick applied fairly rapidly and a sharp attempt then made to reverse the movement a very high resistance would be felt. It was thought that this must be the explanation of the very high but ineffective stick force recorded during the carrier incident.

Without delay, the viscous damper, redundant from its intended function, was removed. Immediately, pilots reported some stick sensitivity, and degraded harmony with the aileron control. The damper was refitted, this time between the stick and the non-linear gear. All was well, with the damper fulfilling an entirely different function from that originally envisaged.

Turning now to lateral control, the original fit was for an aileron authority of ±17° with simple spring feel, a stick travel of 40°, with a non-linear gear. A sharper gearing proved to be necessary for low-speed work, and changes made in the cockpit limited stick travel to 25°. No suitable compromise of gearing could be found to cover high-speed flight and the coarse movements necessary when flying through the turbulence behind the carrier in the final stage of approach. A bowden-cable-operated change of gearing eventuated, where with stick travel limited to 25° aileron authority in the high-speed gearing was limited

to 12°. Autostability was found to be more essential on the ailerons, and two separate gearings, selected by a switch in the cockpit, were made available for use at speeds above and below 300 knots, respectively. In the original design the autostabilization system was powered from the port (left) flying-control system. This remained the case for the tailplane, which was shown to be non-critical at all speeds, and also for the rudder where a separate standby system was inserted into the input circuit. To improve the integrity of the aileron autostabilization function, the port and starboard aileron power units were connected to different flying-control hydraulic systems.



Buccaneer flying control characteristics.

Little development was required in the rudder circuit and autostability gearings were quickly established, but a duplicate standby unit was added to cover failure of the main system, autostabilization being considered vital during the final approach to the carrier. Linear gearing was retained throughout, although the slope was changed and q-feel added, this being felt on top of the spring feel force above 150 knots. This gave a pedal load, for 2.5° rudder deflection at maximum EAS, of 150 lb. Maximum rudder deflection, pedal force permitting, was set at 30°.

The final standard of flying controls, which has been the subject of much favourable comment by all who have since flown the Buccaneer, was only achieved as the result of an intensive flight programme, mainly on XK 486 and 489, and with a major and constructive contribution from the test pilots. One of

them, J. G. 'Bobby' Burns, wrote a thesis on it to obtain his AFRAeS, and this remains a valuable source of reference.

In the discussion period after one of my presentations at St Louis, the then Project Engineer for the Phantom, Dwight Bennett, and who just previously had been responsible for fitting a fly-by-wire system to an experimental Phantom, asked me how we had managed to get the flying controls of the Buccaneer to such a satisfactory condition. When I replied 'the hard way' he smiled, saying that if I had given any other answer he would not have believed me.

Failures during the development programme were mainly confined to leaking seals, although their effects could be embarrassing. Two unique failures do stand out, and both in different ways affected the same subcomponent. With autopilot selected, the input circuit was earthed by engagement of a plunger called the differential lock. This made autopilot demands visible by stick movement.

The first incident occurred on XK 489 with G. R. I. 'Sailor' Parker at the controls, who on a final approach at RAE Bedford reported a major restriction on the tailplane controls. Somehow he landed the aircraft safely, and subsequent ground investigation showed that the potting which surrounded a coiled restrictor had collapsed, allowing excessive hydraulic fluid to pass and cause the differential lock to engage. Once this had happened, pilot stick movement merely stretched the input circuit cables. It was fortunate that the trimmed position of the tailplane at the time of the failure, coupled with manipulation of the throttles and the availability of the long runway, enabled the aircraft to be landed. Of course the potting was immediately modified.

The second incident occurred on XK 486, but with Sailor Parker again at the controls. He suffered a restriction on the aileron controls, and diverted to make a safe landing on the long runway on the disused airfield at Elvington. The cause has never been explained to the satisfaction of the specialists, but I saw the condition reproduced on the flying-controls rig at Brough during the post-incident investigation. A leak in the flying-control hydraulic system had been discovered on 486, and it was shown on the rig that, as the draining system was nearly out of fluid, an emulsified mixture of hydraulic fluid and air caused the differential lock to pop in and out erratically. Once the system drained dry, normality returned.

Sailor did remark that if asked in advance which was worse, failure of the tailplane or the aileron controls, he would have unhesitatingly said the tailplane; but from his experiences this was not the case. He also said that, having brought both of these aircraft down successfully under rather hairy circumstances, the next time major troubles broke out on him in the air he would bale out, and he did.

It was strange that on several later occasions Sailor reported minor control restrictions which we were never able to reproduce on the ground. It remains a mystery whether they were imagined or whether Sailor manipulated the controls in a manner which caused trouble. Sailor was killed on 19 February 1963 while testing the 19th production Mk 1 aircraft, XN 952. Completing the statutory half-loop and roll off the top, the aircraft continued to roll several times, suffered roll-inertia coupling and loss of control; it crashed on the airfield, killing both occupants. Did Sailor suffer yet another control restriction, or was there another reason for the incident? We shall never know.

Second Phase Trials, March 1959-April 1960

The period March 1959 to July of that year saw a rapid expansion of the fleet, XK 490, 491 and 523 being added, with the intention of rapidly increasing the extent and breadth of clearance. XK 489, having demonstrated the satisfactory rotation of the bomb door in flight and played its part in flight-control development, went as planned to RAE Bedford for arresting and catapult proofing and clearance, all of which was completed satisfactorily.

XK 490, intended for armament carriage and release trials, found itself short of role equipment and so was deployed on handling and cooling system trials, the latter including a sojourn in Malta. This made it obvious that a great deal of re-engineering was required on the cooling system. Not only did a new and improved cold-air unit and its control system result, but an entirely different distribution of cooling air in the radio bay was designed, the air being ducted to the individual items of equipment rather than being discharged in bulk. This revised system took a considerable time to develop, prove and introduce into production aircraft; indeed, it did not make the build of early production models.

XK 491, for autopilot trials, was also the first aircraft to be fitted with the air-turbine alternator and its standby inverter, all previous aircraft having just the two 6-kW generators with inverters supplying AC. This alternator had been giving considerable trouble on the bench, and it seemed too great a risk to fit it as the primary source of AC for the aircraft. At the same time, there is no real substitute for the experience of operating in the true environment. The electrical design staff attached to Flight Development produced a loading mat fitted on to the inside of the bomb door, so with the ATA connected to this dummy load, and the earlier system providing electrical power to the aircraft systems, the new system took to the air. Several months of flying followed before we had the confidence to put the ATA on line (and then not without some misgivings) and then proceed with the autopilot trials.

It was during this period that XK 523 emerged ready for initial flights. Hitherto, wheels, brakes and tyres had all been supplied by Dunlop, but it was ruled that an alternative source of supply was to be investigated. Thus 523 found itself with a trial installation of Goodyear equipment, which included a new type of anti-skid system with an electronic control box signalled by a mainwheel-driven generator. With vivid memories of 486 taxi tests, a cautious approach was taken with taxi runs up to ever-increasing speeds. On the first run, to a relatively low speed, as soon as brakes were applied the aircraft porpoised wildly. The Goodyear designer was sent for, but remained puzzled. Further tests were made without success. As pressure built up, with the prospect of the programme flight date not being met, top brass assembled and increased the pressure further.

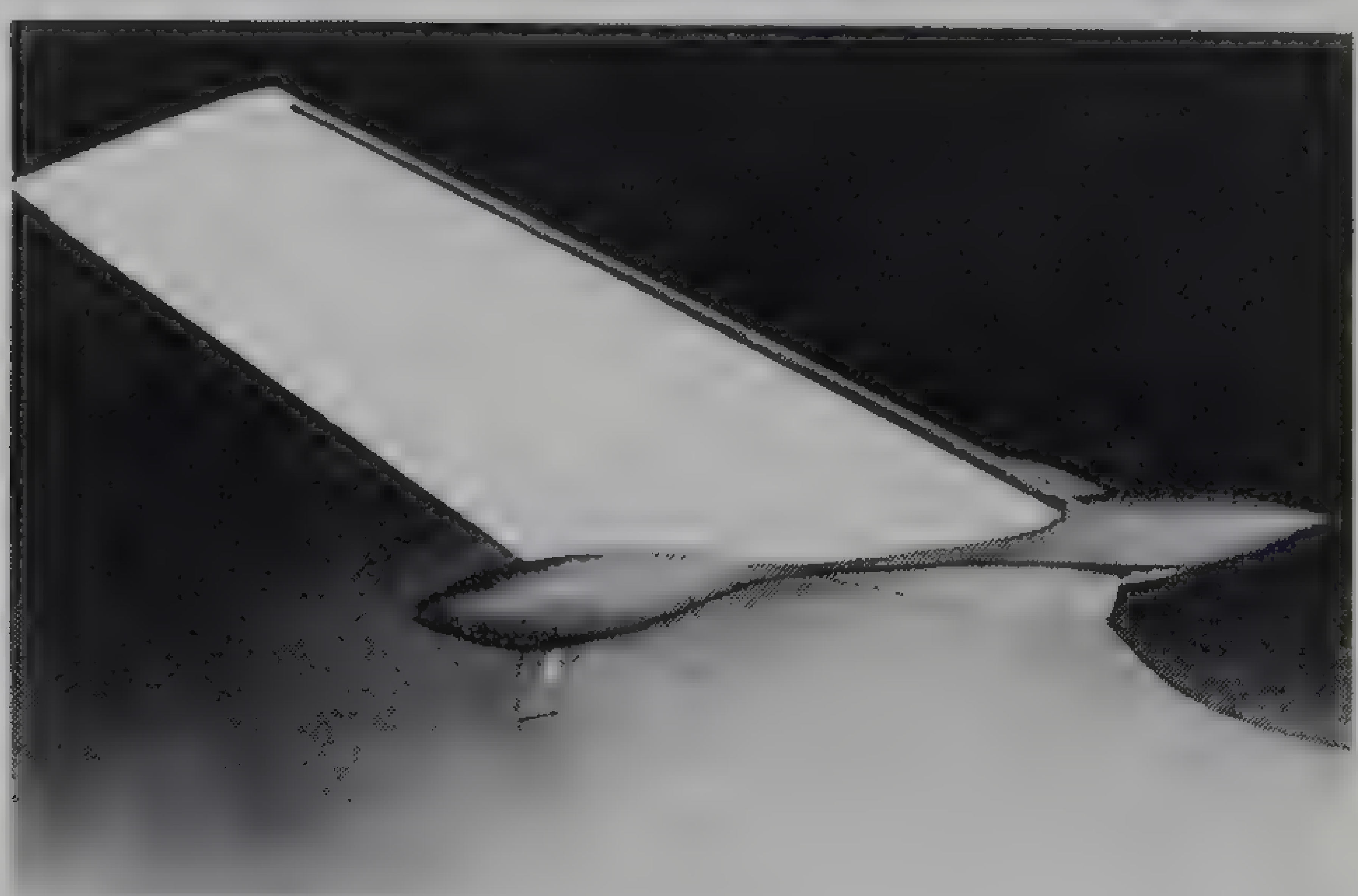
One incongruous sight during this phase, investigating possible slippage between the mainwheel and the generator wheel, was a valuable unflown Buccaneer jacked up with a mainwheel driven by a belt from an industrial vacuum cleaner, and with a man pouring water from a watering can over the driving track for the generator wheel.

The problem remained unsolved; chairing a meeting of all concerned, I decided that the flight date had to be delayed. At this point, the Brough Production Director — who, to his credit, had never missed a programmed

flight date — got up and walked out in disgust. With this decision made, some of the immediate pressure was relieved. By now it was lunchtime, so I adjourned indefinitely to give people time to think in peace. As can so often happen, by early afternoon Goodyear had solved the problem; the system was modified and the first flight of XK 523 took place only a few days late. In fact this new system was so successful that Goodyear won the production order, and their equipment has been fitted to all service Buccaneers.

Engine problems permitting, the first three aircraft flew perfectly well up to a maximum speed and Mach number. In contrast, XK 489 and 490 showed a tendency towards directional tramping above 520 knots, or 0.9 Mach. This was accepted for a time but, when XK 491 exhibited severe tailplane shake at similar speeds, investigation could not be delayed. It was deduced that a shock-induced separation in the fin/tailplane junction was the probable cause, and that a

Original standard



Final standard

Buccaneer fin tailplane junction.

waisted bullet should improve the situation. I was aware that a major redesign of the fin had been done at the London Design Office and introduced on XK 489. The skin joint fitted to XK 486, 487 and 488 to accommodate tailplane rotation was in the line of flight, and the whole surface was completely smooth. The telescoping ducting for the tailplane blow was considered to be unsuitable for production (known affectionately as the trombone). The London redesign

had, in the interests of weight-saving, thickened the top of the fin and also made the skin cut for tailplane movement diagonally up the fin. Looking at this in the hangar it could be seen that there was a large gap which was bound to cause trouble. The final fix, in addition to the waisted bullet, chamfered over this gap by a spring-steel rubbing strip.

This did not fully cure the problem but raised the onset to above the penetration speed, and so was acceptable. It was early 1961 before the modification was agreed, and it was only just possible to fit it in time for the final pre CA-Release trials, and to the first aircraft to be delivered to the Royal Navy. Years later, in dealing with a problem on delivery testing on a production aircraft, the complete cure was discovered. Stiffening of some linkages in the final stages of the rudder input circuit would have cost very little to fit, but the cost of demonstration trials caused the service to reject it, as they felt that the condition could be lived with.

XK 523, having completed the first phase of the radio trials, was allocated to join 489 on the initial carrier trials scheduled to take place on HMS *Victorious* in October 1959. XK 490, still unable to start its armament programme, was employed on general handling and then positioned at Boscombe Down for a flight assessment by an American NASA pilot, W. H. (Bill) Alford, the US Government having contributed to the cost of the NA.39 development programme. This assessment was taking place in October, just as the deck trials were scheduled to start, and XK 489 was positioned at Boscombe Down for the pre-trials work up.

I was due to travel to Portsmouth to embark on *Victorious* on the Monday, when on the Sunday morning word reached me that a malfunction on 489 had broken the wing-fold doors, and that a specialist repair squad had to be rounded up and rushed down. Midnight saw me in a requisitioned company car driving through the night to deliver the repair gang at 6.00 am. After lunch on 12 October, XK 490 took off, and just as I was about to leave for Portsmouth we learned that it had crashed in the New Forest. Derek Whitehead and I drove to the scene. My assessment (proved to be correct) that there would be no deck trials until the accident could be explained caused me to remain at Boscombe Down.

I soon found myself attached to the Accident Investigation Branch (AIB) officer allocated to the investigation, Arnold Broomfield. Among other things, we toured the countryside interviewing eye-witnesses. This was interesting, for these country folk were most observant. They had peculiar ideas of what they had seen, but knew exactly where. By simple trigonometry and our own reconstruction of what they had in fact seen we were able to build up a useful picture.

The aircraft had dived into the ground, adjacent to a stream bed, at an angle of 60°, inverted. The centre fuselage had exploded, but the rear fuselage and airbrake mechanism had gone on down, taking the instrumentation recorders with them. These had to be recovered. With Eric Owen from the Engineering Division of Boscombe Down, I found myself supervising and assisting the professional wreckage recovery crew. Everything we dug up was labelled and laid out on the ground for transportation to Farnborough, to be reconstructed and studied by the famous organization headed at that time by Fred Jones. In the end we were shinning up and down ropes through water and fuel-soaked

mud to the bottom of a 35 ft-deep pit, where we finally found the recorders and were able to start the analysis.

Our reconstruction from the eye-witnesses proved to have been correct, but it took study of the records to find the reason. Alford had exceeded his briefing, and investigated a condition not then explored in the firm's trials by flying in the low-speed blown condition and simulating single-engine conditions. He stalled at an altitude of around 10,000 ft, too low for recovery. Both occupants, Alford and his Blackburn observer, John Joyce, ejected; but with the aircraft semi-inverted and descending very rapidly they were outside the ejection envelope and lost their lives.

Whilst I said that the cause was understood, the precise reason for its happening remained a mystery. Long after, we had several cases of a non-return valve failing open, which if it had happened under the XK 490 conditions would have led to a major engine malfunction, leading to the result as experienced. The loss of 490 did not impede the armament trials, for by the time that the necessary equipment became available XK 523 with the planned slack in its programme was able to take up the load.

January 1960 saw the deferred deck trials take place on HMS *Victorious*, with XK 489 again already based at Boscombe Down but with XK 523 still at Holme on Spalding Moor. I duly embarked on HMS *Victorious*, expecting to be technical observer and adviser. I was shaken to be told that I was to supervise everything except for catapult launch speed decisions. Both aircraft were to be maintained by Company personnel, with assistance from C Squadron, Boscombe Down engineers. Aircrews were to be a mixture of Blackburn and Boscombe Down personnel.

On the day when the trials were to start, *Victorious* was steaming in Lyme Bay, but Boscombe Down was completely snowbound, and neither XK 489 nor its ground crews could get out. We had the ground crew for XK 523 aboard, none of whom had been on a carrier before and their chargehand was amongst those stranded at Boscombe Down. All was not lost, however; XK 523 arrived direct from Holme on Spalding Moor, piloted by Derek Whitehead, and made the first deck landing. It was to be two days before XK 489 and its complement of personnel were able to join the ship.

Not unnaturally, initial flights were being made at light weight, with only partial fuel load. At this stage we could not guarantee the accuracy of the fuel proportioners to draw evenly from each tank, nor should one tank become inadvertently empty, the integrity of the low-level float-switch-operated fuel-no-air valve. Two precautions had been taken on this account. A flowmeter had been shipped aboard and positioned on the deck to indicate exactly how much fuel had been added, and the tanks were to be chain-dipped before and after each flight. This was done on deck in a howling gale by a ground crew new to the environment whose chargehand was, at first, stranded ashore.

In spite of the adverse weather, the trials in the main went very well, and the unserviceabilities that we had (while inconvenient) were not serious. But one major crisis did arise after several flights had been made.

Chain-dipping of the tanks showed that something was amiss. While the results of the dipping were being studied, XK 489 was taxying from an arrested landing forward to the catapult for a further launch, when I was literally shouted at: 'Are you going to let him go or not?'. Under this duress I replied, 'Yes, for

one circuit only, and if he misses the arrester wires, divert him ashore.' He did his circuit and, to my relief, landed safely. At this point either losing my nerve or regaining it, depending on your point of view, I declared the trials suspended as we just could not operate with an unknown but low fuel state. After some time the ship's refuelling officer joined us, offering to pour in pre-measured fuel manually, with the aircraft down in the hangar. At this stage, having studied the chain-dipping results more carefully I expressed the view to the Boscombe Down Engineering Officer that, rather than putting fuel in, they were at times taking it out! His reaction was violent, and included the offer to buy me a pint of gin if my conclusion was proved to be correct.

The ship's refuelling officer had, however, been triggered by my statement, and soon afterwards came up with the answer. Refuelling by our ground crews had always been done on an airfield using a Trent refueller. Having completed the operation, they invariably left the refueller in situ, with the hose still connected to the aircraft until either the aircraft or the refueller required to be moved. They had followed the same practice on the ship and left the aircraft with the hose still connected. What they did not know was that the aircraft fuel was pumped up from the bowels of the ship and that, when the pump had ceased delivery, the system sucked back to remove the standing head of fuel in the line. Prior to this crisis it had not been left on long enough for the effect to be noted. Fortunately, the speed with which this problem was solved did not delay the trials for more than an hour, but it could have been very serious.

On the first day of the trials, I was up in 'Flyco' (flying control) and the aircraft had been taken down to the hangar for some minor rectification work. The Captain asked me how long we would be before the aircraft would be again ready for launching. He pointed out that he had a small problem, as the carrier was steaming into wind but also heading for the coastline, and he wanted to be in the right position at the right time. This put me under much heavier pressure than I had ever been before, but I was duty bound to give an answer. Taking a deep breath I gave a prediction which, by sheer good fortune, turned out to be very nearly right!

When we had both aircraft operating, to maintain momentum, we tried to arrange it so that never more than one aircraft should be in the hangar on maintenance at any given time. My normal position was up in Flyco, two decks above the flight deck. The hangar floor level was three decks lower. The Blackburn service representative, Ted Mason, and I had to pay frequent visits to the other station, and the number of times we crossed one another at the double on such travels became a source of much hilarity. One can safely say that the environment, despite the splendid co-operation of the ship's crew, was decidedly hostile. The normal ship's operating routine is executed at a much higher pace than is comfortable for an experimental trial. This made it an onerous assignment, but, with the results of the trial encouraging, a satisfying one.

In spite of the various difficulties which arose, and the severe weather which ruled out flying for roughly half the time available on the six days allocated, the attainment of 31 launches and arrested landings was a creditable achievement, and the results a favourable pointer for the future. Several other deck trials were to follow, before a final operating clearance was to be given.

Engineering deficiences shown up on these trials led to major changes to the arrester-hook system design, alteration to the rebound ratio of the under-

carriage, changes to the tailskid damper and shoe, and alterations to control and autostability gearings. None of these impacted on the basic design of the aircraft, and were relatively easily incorporated and proved on the later deck trials.

Other matters which affected piloting techniques for ship operation had also to be dealt with. AOA indication, plus audio warning of approach to a dangerous value, proved to be a vital aid. Though fitted initially purely for trials purposes, it became a standard fit. Catapulting at or near to minimum launch speed needed accurate setting of tailplane trim angle, to avoid the need for any immediate post-launch corrective action by the pilot — which could, as experienced on XK 529, be disastrously wrong. Markings on the fin for independent checking by the ground crew were added, and the input circuit balanced to allow the hands-off launch technique to be made the standard mode.

The new integrated pilot's display included a combined true airspeed and Mach function, using a moving strip (tape) indicator. This proved to be unsatisfactory for the approach to deck landing; not only was it insufficiently accurate, but it did not indicate rate of change of speed, which helped the pilot to make fine adjustments. The so-called 'retrograde step' of adding a conventional twin-pointer ASI mounted on the coaming proved to be completely satisfactory. Thus the initial deck trials of January 1960 provided a firm base for subsequent trials to clear the Buccaneer for deck operation by the required date.

The end of the period under review saw XK 487 complete its programme of flight-envelope structural clearance. It was detached from the NA.39 programme to be the trials vehicle for the Ferranti forward-looking radar being developed for the TSR.2. XK 486, whilst continuing with general handling and flying-control development, also had an autopilot fitted to assist the primary autopilot development aircraft, XK 491.

At this stage two major problems were limiting exploration of the regime above about 500 knots EAS. One was the aerodynamic problem of the fin/tailplane junction. The other was handling problems with the Gyron Junior engines, where malfunctioning of the inlet guide vanes under aerodynamic loading caused the engines to stall, with a loud and disconcerting bang. Various detail improvements were introduced by de Havilland to both the controller and the operating jacks. These were sufficient to allow the programme to continue, but were inadequate for release to the service. De Havilland therefore set about producing a new standard of engine designated Phase 3, but this was not to become available until April 1961, the date set for CA Release. We thought that we could just achieve a July target for initial CA Release, and, after some high-level rumblings, the revised target date was agreed and the programme rearranged accordingly.

Third Phase Flight Trials, May 1960-March 1961

Apart from resolution of the fin/tailplane junction and engine problems, stores carriage and release (mainly on XK 523 but also at times on 489) was in this period one of the primary tasks. Approaches to the stall, particularly in blown configurations and using telemetry were included in the programme for 489, although engine behaviour limited the minimum speed to which we dared go as there was always the risk of a double engine flame-out, with total loss of control. Autopilot and autostability development continued on XK 491 and 486.

Meanwhile, as a result of the outcome of the trials and also of pilots' comments, a new standard of Buccaneer had been designed, and was to be introduced on the eighth aircraft. The build of this aircraft, XK 524, was delayed by some eight months to accommodate this, with a corresponding delay on subsequent aircraft.

The redesign included a number of structural changes to reduce weight, major changes in the cockpit including integration of flap, aileron-droop and tailplane-flap controls, strip fuel gauges to indicate individual tank contents, a final standard of flying controls and autostability gearings, and numerous minor refinements. It was truly the first model of the production Buccaneer. Among other things, it had to repeat the handling trials and also, because of the structural changes, repeat the flutter and straingauge tests. It was therefore a vital element in the tight programme to be achieved to lead to the targeted CA Release. Not only had it to repeat the earlier work on the clean aircraft but cases with externally carried stores had also to be covered.

Then the last thing we wanted happened! After very few flights on this aircraft, disaster struck. Failure of a hydraulic pump resulted in severe contamination of the entire hydraulic system, which had to be stripped down component-by-component and cleaned. This led to a three-month delay on the already critical programme. Fortunately, once restored to flight status 524 proved to be a very reliable aircraft; it flew intensively and enabled us to achieve our aims.

During the period under review XK 525, with the first complete weapon system, flew and began shakedown trials, and XK 526 and 528 were despatched on programme to Boscombe Down for engineering and radio/navigation assessments. XK 527, on handling and performance assessment, operated in parallel with XK 524, spending alternate periods on the firm's programme and at Boscombe Down. Towards the end of this period, XK 529 and 530 became available. Although earmarked for weapon system and special armament work, respectively, they were diverted to ease the congestion on the basic CA Release programmes. Unfortunately XK 529, the 13th aircraft, was a rogue. Its serviceability was a disaster, and it took many weeks of effort to get it on a useful programme. In fact this happened only when we stopped referring to it as No.13 and rechristened it 12A.

At times we had 11 Buccaneers in the hangar at Holme on Spalding Moor, mostly to differing standards and on different programmes. The organization to handle this operated around a weekly meeting with works, inspection, flight test and engineering support staff. Two senior executives responsible full-time for the programme as a whole acted as chairman and secretary of this meeting. The secretary, apart from preparing the programme, chased throughout the company to ensure that all decisions were acted upon in the timescale required.

Experience had shown us that development aircraft could spend up to 40 per cent of their time on modification and rectification work. We called these periods stand-downs, whereas at Warton they used the double opposite and called them lay-ups. We also found that, for major items at least, three to six months prior notice was necessary to ensure that all of the bits would be available when it was time to fit them.

Another factor which impeded progress at times was the servicing schedule. Based on the pattern operated by the Services, this was on a calendar basis.

Thus, an aircraft could just complete a long stand-down and then be due for servicing. This had to be, and was, changed; but not before several frustrations.

The overall programme planning assumed an average flying rate of ten hours per aircraft month. With 40 per cent of the time on stand-down, this meant that a rate of 17 hours a month had to be achieved by each aircraft when it was at flight status. On some occasions 25 hours a month was achieved on individual aircraft, but the overall average flying rate ran out at about eight hours per aircraft month. Nevertheless, enough progress was made in this period to leave the target date of CA Release and delivery of the first two aircraft to the Royal Navy possible.

One key to this was the delivery of an acceptable standard of engine. Otherwise, with the resolution of the fin/tailplane junction problem, structural proving and general handling work proceeding well, clearance of the basic airframe looked healthy.

The armament and carriage trials went well, with just a few problems. With large and well streamlined stores carried on the bomb door, it came as no surprise for heavy buffet to be experienced with the door open. Detachable fairings to smooth the flow between the store and the airframe had been prepared, and when fitted they eliminated the problem. Release of such stores was entirely satisfactory.

Carriage of conventional stores on the four stations on the bomb door caused no problem, but on release they pitched and jostled, giving an inconsistent strike pattern. Angling of the carriers and minor changes to the release intervals were introduced, to give an acceptable situation.

Carriage and release of wing-carried stores with a pylon-mounted powered release unit was completed without any problem. The one wing-carried store that was not mounted on a pylon was the overload fuel drop tank. For mimimum drag, and hence maximum range, this was similar to that used on the Victor, snugged up to the undersurface of the wing with a Küchemann fairing between the tank and the wing leading edge. To obtain satisfactory separation on jettisoning, an elaborate scissors-type mechanism and rear hook were designed to get the tank away in the right attitude. The result was a very expensive tank, but it worked well. Later this led to a conversation with Sir Sydney Camm, in his capacity of Design Director of Hawker Siddeley Aviation. In his typical manner he set about me in no small way concerning this 'expensive rubbish' compared with the simple welded drop tank as used on the Hunter, and had I 'never heard of value engineering'. The relative cost factor was about seven to one, so at first glance Sir Sydney had a point. I pointed out to him that, due to the relative drag of the two tanks, range with our slipper tanks retained was at least as great as it would be with the Hunter-type tanks dropped when empty, and that a greater range could be achieved if required if the slipper tanks were dropped when empty. It would not take many sorties for the slipper tank to break even on cost, and this seemed to me to be value engineering. Gentleman that he was, Sir Sydney — having made his attack and received an answer — graciously conceded. These tanks worked perfectly on the Mk 1 Buccaneer, but as related later, the low-drag Küchemann fairing was to have an unfortunate effect on the Mk 2.

The other concurrent major area of attack was on the autopilot. This was to have conventional navigational modes, but including the high-speed low-level

case. It was also intended to provide an automatic store release manoeuvre of a half-loop and half-roll off the top, for 'tossing' a nuclear weapon. The autopilot computer also controlled the autostability modes. Having finally established autostabilizer gearings, runaway cases had to be cleared, but this was completed without difficulty.

Selection of gearings to cover all cases, and determination of settings for the limit switches, was by no means an easy task. It soon became apparent that the limit-switch settings to suit the programmed toss manoeuvre were totally incompatible with settings appropriate to the navigation modes; but it also became apparent that the half-loop and roll off the top manoeuvre could be executed quite satisfactorily manually, so the programmed manoeuvre requirement for the autopilot was dropped.

During this phase of autopilot testing, investigating desirable gearings and testing them with tolerances about what was of necessity a very tight value, XK 486, the very first Buccaneer, with Sailor Parker at the controls, was lost under interesting circumstances. Flying manually in cloud, Sailor felt the aircraft rolling. True to his earlier remark, he decided to eject, but before doing so he closed the throttles. The aircraft then flew in a gentle spiral, finally touching down at a shallow angle on a hill-top, shedding bits over half a mile or so until what was left was catapulted across a valley to come to rest on the other side.

What transpired from the investigation was that the artificial horizon, for which at that time there was no standby, started to go round spontaneously. The rolling which Sailor had felt was in fact due to instinctive movement of the stick to follow the artificial horizon. Thus was a highly experienced and first-class test pilot fooled. The loss of XK 486 at this stage of the programme was in fact of little embarassment. As yet another example of the baleful extent of Murphy's law, Sailor's transmission that he was ejecting coincided with a transmission to him from Holme on Spalding Moor, which blocked it out. It took a telephone call from another air-traffic control who had heard Sailor's transmission to alert us.

Autopilot development and clearance continued on XK 491. At first there was no real problem, but suddenly the height lock at high speed and low level became unbearable. It was known that the height-lock transducer could be g-sensitive, and we thought that the effect of turbulence could be the cause of the trouble. Investigation of this aspect eliminated it, leaving the cause a mystery. The final solution came as quite a surprise as a pitot/static position error. The PEC (position-error correction) curve is normally regarded as single-sided, but it is in fact a symmetrical curve. The probe was riding at an angle near to zero, and to add to this the sensing holes in the probe were insufficiently sensitive. By tilting the angle of the probe upwards, and fitting a probe with more sensitive holes, the problem was overcome, and the autopilot programme ran through to its conclusion.

Included in the handling trials which had to be completed before CA Release was an extensive programme on roll/inertia coupling. The technique was, under predetermined flight conditions, to apply a step input of a given magnitude to the ailerons. This was done with the aid of a dog chain, fixed at one end to the stick and at the other end, with an appropriate number of links, to the fuselage side. To cover all of the cases was a tedious business, and rather distressing for

the flight-test observers. Eventually all of the cases were covered, and the clearance was assured.

In one of our many exasperations with Boscombe Down pedanticism, it was pointed out that if, following an accident, they were found to have paid inadequate attention, things could be bleak for them.

Having had their Buccaneers for some time, The Royal Navy Intensive Flying Trials Unit, 700Z Flight, prepared for an air display, and thought up a new and attractive manoeuvre. This comprised an eight-point roll, interrupted at the halfway stage by a 360° maximum-rate roll, followed by the remaining four points. The first time this manoeuvre was attempted the aircraft returned to base with the flaps broken from their jacks, and the fin bent to the extent that the fin attachment bolts to the fuselage could not be withdrawn. It was a highly skilled pilot who had brought the aircraft back!

For the benefit of the uninitiated, roll/inertia coupling is a function of the inclination of the axis of the aircraft to the line of flight and of the rate of roll. In inverted flight the inclination of the aircraft axis is some 6° greater than in the normal 1g condition for the same speed, and this was sufficient to bring on coupling. None of us thought, when doing our roll/inertia coupling tests, to start from 'the wrong way up'. We had more sympathy for Boscombe Down after this incident.

March 1961 saw us with most of the development work necessary for the first CA Release either done or nearly completed, although with a very heavy load on Boscombe Down to complete their tests and paper work. At Blackburn we had the problem of bringing both the Boscombe Down and the first Service aircraft up to the required standard; but, most urgent of all, Phase 3 engines were just becoming available and had to be fully explored. The co-operation from Boscombe Down in trying to clear the highest standard was exemplary, but it left us preparing at risk the initial Service aircraft to a standard which had yet to be cleared, there being insufficient time between clearance and delivery dates. In the event, all went as well as we had hoped and planned.

To CA Release, July 1961

By late March 1961 much of the clearance work was done, but Boscombe had a number of loose ends to tie up. XK 526, for engineering assessment, was scheduled to undertake a tropical trial in Singapore in the summer of 1961, but the results of this could not affect the initial CA Release.

XK 525, initially at Holme on Spalding Moor, but mainly at West Freugh (Scotland), and XK 528 operated from Boscombe Down, both on overall weapon-systems work, were to be engaged on ongoing programmes well into the future, but at least they were able to produce a switch on clearance for the various equipments. The main problem for XK 524, 527, 529 and, until it resumed its special armament programme, XK 530, was to extend the envelope clearance to the highest speed possible, complete any outstanding handling trials and, most importantly, establish the necessary level of confidence in the Phase 3 engines. At a later date these aircraft were to undertake extended deck trials, during which XK 529 was lost, as previously described.

With the new Phase 3 engines just fitted to two aircraft immediately prior to Easter 1961, with limited works support available, a small group arrived at

Holme on Spalding Moor to get in as many flights as possible. To our disgust, we spent the entire time taking engines out and putting them in again. In view of the limited works support, some of us spent more time close to the operation than would normally be the case, which turned out to be a blessing in disguise.

One of the new features of the Phase 3 engines was turbine blade cooling, which in the interests of fuel economy was to be used only with blowing on. Indication to the pilot, and also the signal to the engine control system that blade cooling was operative, were via a microswitch mounted on the periphery of the engine and operated by a linkage from the HP bleed valve in the centre of the engine. Adjustment to this microswitch, which unfortunately was a frequent requirement, necessitated removal of the engine.

The microswitch lay between the heat shield and engine carcase at about the ten o'clock position. Access to it through the heat shield was obtained by removal of a panel fixed by ten bolts around its periphery. Due to the ten o'clock position, and the proximity of the bodyside, the panel could not be reached on one side of the aircraft (access was relatively easy on the opposite side). As the bolts on the forward end of the access panel lay directly over the main-spar ring, this in itself precluded removal of the access panel.

Furious at the delay, I looked more closely at the problem. By moving the bell crank between the operating rod from the engine valve and the microswitch through 180° the microswitch could be brought down from the ten o'clock position to be accessible on both port and starboard installations. This, of course, would still not allow the cover to be removed. There could be little load on the heatshield, so structurally some of the ten bolts must be redundant. To slip the forward end of the panel under a lip in the heatshield and bolt round the other three sides should be adequate, and would permit access to the micro-switch with the engine in situ.

We did eventually get flying with all going well, but the overall engine situation had come under high-level scrutiny. They were well aware of the turbine-cooling valve microswitch problem, and were not prepared to accept it. In a supporting role, I attended a high-level review meeting at which John L. Edwards, the DH Engines Chief Engineer, said the improvement to the TCV situation would involve major redesign in the heart of the engine, and would take many months. With considerable temerity, I announced that I thought that I had a simple solution. To his credit, John Edwards offered to send a senior engineer to investigate. My scheme was then adopted, bits quickly made and that particular crisis averted, so the working Easter weekend was not completely wasted.

The Phase 3 engines, as flown, appeared to have overcome the problems encountered on the Phase 1 engines, to the extent that CA Release should be possible. The Ministry of Supply remained suspicious, and took a great deal of persuading that our outlook was not unduly optimistic. They finally called a meeting to be chaired by Peter Lloyd, DGEng, to make a final decision.

During the final run up to CA Release one of the quarterly progress meetings at the Ministry took place at which two outstanding incidents occurred. The first was when the executive responsible for weight estimation and control, in giving his report, announced that we were 'meeting our weight-growth target'. Of course the target is zero, and what he had meant was that the recorded weight growth was within the statistically predicted probable growth. The second was

when the Experimental Manager, who had an obsession for fine detail, in the course of his report started to say that the fin/tailplane bullet was being fitted to XK 531 and 532 prior to delivery. Remembering that the Project Director, who was chairing the meeting, had previously ruled that fitment and clearance trials were not practicable within the required timescale, John Stamper and I suddenly had a fit of violent coughing, sufficient to drown the words being spoken. With XK 527 similarly fitted, and Boscombe Down joining in the plot and achieving the necessary clearance in time, 700Z Flight had an additional 50 to 70 knots available to them from Day One.

Thus after trials (in both senses) and tribulations, an effective CA Release was obtained on schedule in July 1961 to enable the Royal Navy to get to grips with their new aircraft, with the remaining four Buccaneers to bring the IFTU up to full strength being delivered as planned.

In 1970, on a visit to RAF Honington with the newly formed 12 Sqn of Buccaneers, I learned that they had been allocated XK 531 for fire practice. Horrified, I pointed out that this was the first Buccaneer to go into service, and suggested that it should be given the honourable position of gate guardian. This, much to my delight, they did. Its brother, XK 532, now fulfils the same function at RAF Lossiemouth.

Postscript to Initial CA Release

Following initial CA Release, trials continued to clear additional role equipment and to do further carrier trials. One or two other problems persisted which, although not directly impeding the early service operation, did involve ongoing development activities.

Flight Refuelling

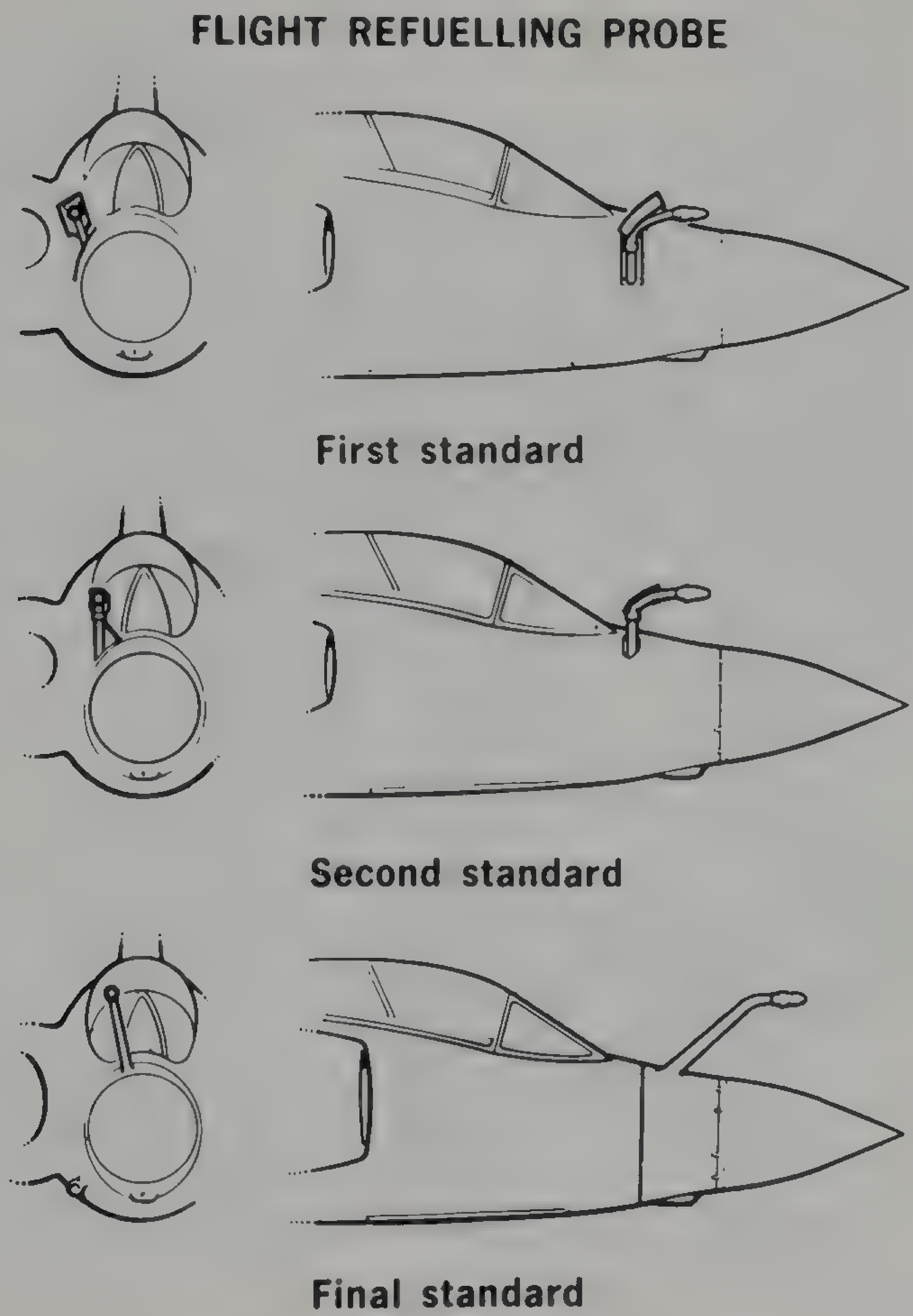
In the original design, every effort had been made to minimize external drag. A fully retractable flight-refuelling probe had been designed which, when extended, came out at about the 11 o'clock position. Retraction rotated it through 90° for it to stow internally athwartships.

Very early in the programme on XK 491 we decided to explore use of the probe in case a major problem arose. Having obtained the services of a tanker aircraft, dry contact trials commenced. At this stage the flying controls were still rather lumpy, and the necessary degree of precise longitudinal control was difficult to obtain. The radial clearance of the nozzle from the bodyside was limited by the stowage dimensions available, as was the fore-and-aft position of the extended nozzle. It was found that, as the nozzle approached the tanker drogue, a bow-wave effect from the Buccaneer caused the drogue to move suddenly such that engagement of the probe was something of a lottery. This was not the only problem, as the presence of the probe or drogue induced a disturbance in the airflow which caused the engine compressor to stall.

Back to the drawing board. A more upright position of the probe, with an increased radial clearance from the fuselage, was found to be practicable with a retractable installation, but only at the expense of a major redesign to reposition installations in the front fuselage. To ensure that this was a satisfactory solution, before embarking on such major changes, a fixed dummy probe was flight tested with apparently satisfactory results. The changes needed to accommodate this

new probe were such that the installation did not appear until the early production aircraft. To our horror, when tested, the situation was little better than with the original installation. Engine banging still occurred, and the bow-wave effect was still present.

This seemed to be about the most intractable problem I had to face, not helped by the fact that our faces were red following a very expensive and



Buccaneer flight refuelling probe.

ineffective modification. In the end we sacrificed our ideas of maximum cleanliness, and adopted a seemingly crude fixed but removable probe, with the nozzle location free of engine banging and drogue jumping.

Aircrew Escape

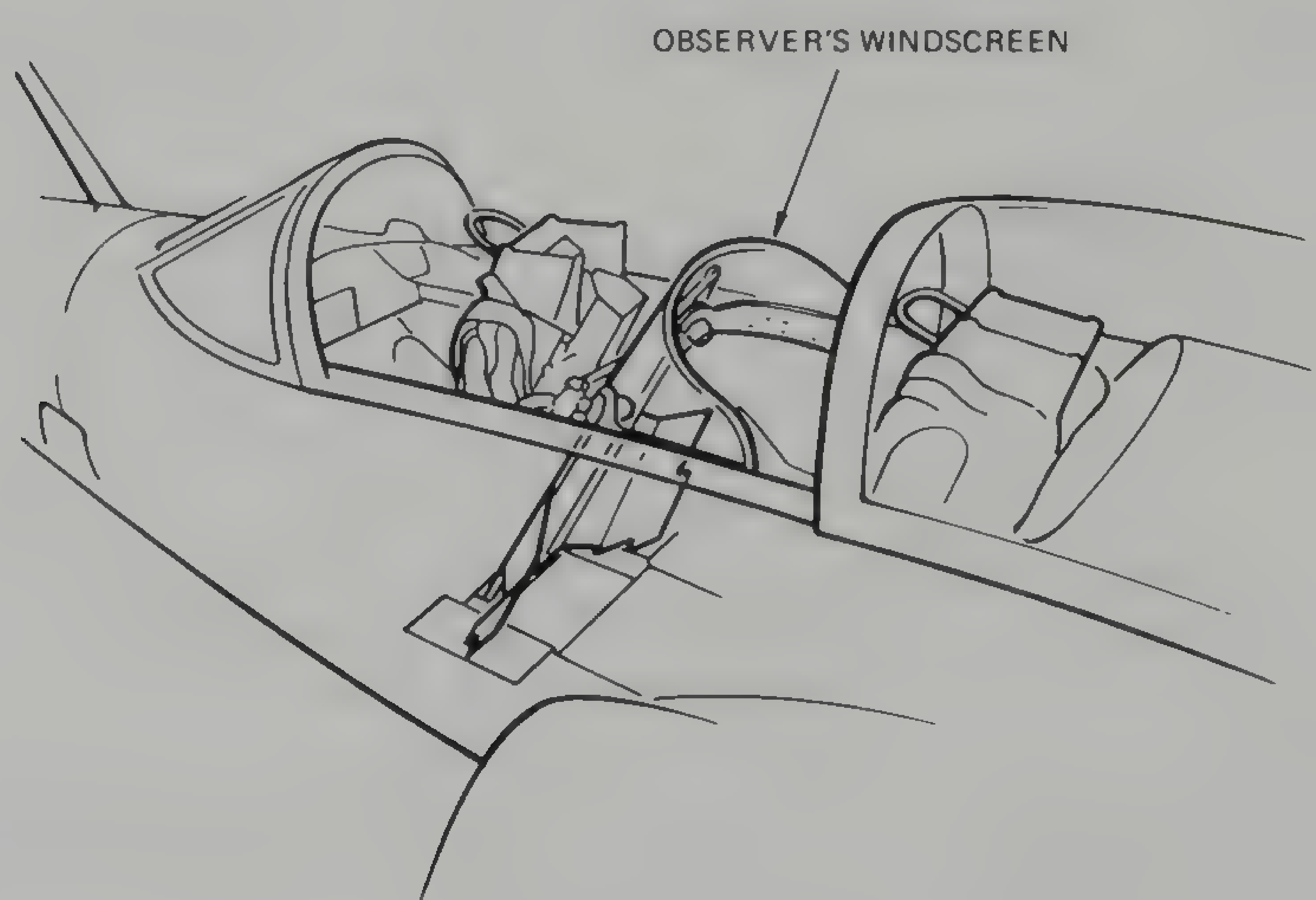
The development of the aircrew escape system for the Buccaneer went through a number of stages, compounded by two sources of particular difficulty. One was the very short time available for escape when flying at high speed at low level. The second arose from the close spacing between pilot and observer, which meant that, of necessity, the canopy had to be a single piece weighing some 200 lb.

The Buccaneer was designed shortly after a number of incidents of inadver-

tent canopy jettison, as a result of malfunction or maladjustment of the spring release systems. The Buccaneer system was specifically designed to make this impossible. With so large and heavy a canopy, gas-powered jettison was essential. The design was such that a notched rail along the canopy edge interlocked with a similar rail fixed to the fuselage. Release of the canopy involved sliding the canopy rail forward to free the interlocking. This was effected by firing a cartridge in a gun; having unlocked the rails, the residual gas power was transmitted via a shuttle valve to operate vertical rams to push the canopy into a fly-away free position. Trials showed that two separate charges were necessary, and that the vertical rams had to be angled rearwards slightly to throw the canopy clear in the static case. With these changes, the canopy jettison system was proved capable of being operated separately in its own right, or as part of an automatic ejection sequence.

The lower the airspeed, the longer the canopy would take to fly clear of the path of the ejection seat. A time-delay built into the automatic ejection sequence to cater for this would have to be at least one second, and this was not a happy situation for the high-speed low-level case.

Prior to first flight, canopy jettison tests had been done in the blower tunnel at Boscombe Down, and these had shown an unanticipated problem. Above about 250 knots conditions in the rear cockpit, canopy off, became very unpleasant. At any higher speed they became virtually untenable, because of very turbulent flow entering the cockpit. Subsequent flight trials with an instrumented dummy

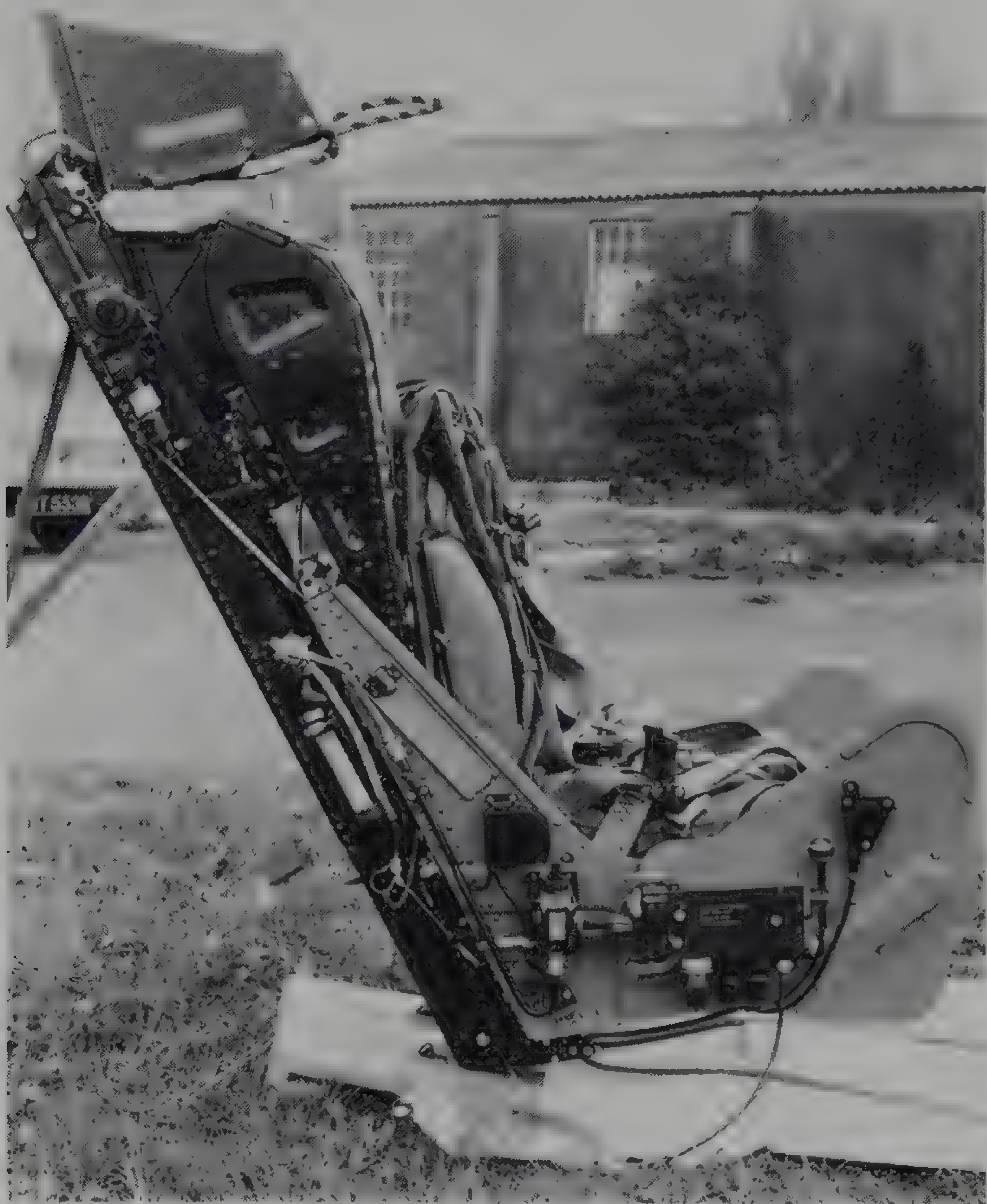


Buccaneer cockpit with observer's windscreen.

in the rear seat investigated the condition at speeds higher than we could attain in the blower tunnel. Attempts at a simple fix, such as a plate screen behind the pilot's seat, produced no improvement.

The decision was then made to make the basic mode of ejection through the canopy, deleting the interconnection between seat ejection and canopy jettison, but leaving the option of manual canopy jettison available to the crew. To make the through-canopy mode feasible, Martin-Baker modified the seat, strengthen-

ing the seat back and adding canopy breakers on top of the seat to clear the way for the upper body, and on the sides of the seat pan to clear the way for the thighs and feet. The modified seat gave the quickest possible exit for the high-speed low-level case, and also ensured that the observer need never be exposed to intolerable conditions.



Buccaneer ejector seat.

Rigorous tests on a static rig at Brough and on a rocket sledge at China Lake in the USA led to the clearance of the system. Initially the ejection seats fitted to the Buccaneer were limited to a minimum speed of 60 knots, but later introduction of the rocket-assisted seat gave a true zero-zero capability. Following a review of test data and safety factors, to assist ejection through the canopy the original transparency thickness of 0.5 in was reduced in two stages to a final thickness of 0.3125 in (5/16).

A review of all ejectons up to late 1966 showed that, up to mid-1964, all ejections had been preceeded by canopy jettison, although in all but one case ejection had been made at low speed. In the remaining case the canopy had been jettisoned at about 430 knots. The observer was then unable to reach the seat firing handle until, as a result of the throttles having been closed before the canopy was jettisoned, speed fell off such that he was eventually able to eject.

Over the next two years 60 per cent of ejections were through the canopy, and as far as the system was concerned everything worked perfectly. Questions, however, did arise where in two cases the aircraft had been in a spin at the time of the ejection, with the crew being thrown about somewhat. For the conditions encountered ejection had been too late and hence fatal, but there were indications of damage to the helmet. Bearing in mind that all development had been done in the straight and level condition, some doubt arose on the adequacy of the punching of the initial hole to cater for all possible situations, so we went back to trying to improve the canopy-off conditions.

It was at this stage that we received invaluable help from Joe Boulger of Folland, who had met and solved a similar problem on the Gnat. With a pressure depression formed in the front cockpit behind the windscreen, the turbulent flow was coming not only from over the top but also over the sides of the rear cockpit; it then circulated forwards into the front cockpit, finally producing an updraught around the pilot. Joe recommended fitting a wrap-round screen for the rear cockpit and effectively sealing any gaps within the cockpit between pilot and observer. This was demonstrated in flight up to full operational speed, and then made a standard fit in all Buccaneers. However, in practice, ejection through the canopy has remained the preferred mode of escape.

Being a naval aircraft, the Buccaneer had to cater not only for the on-the-ground and the airborne cases, but also for the underwater case following a ditching. For this, naval aircraft which had ejection seats had an extra system which operated the seat gun by compressed air, rather than by the cartridge. Firing was initiated by a depth pressure-sensing device.

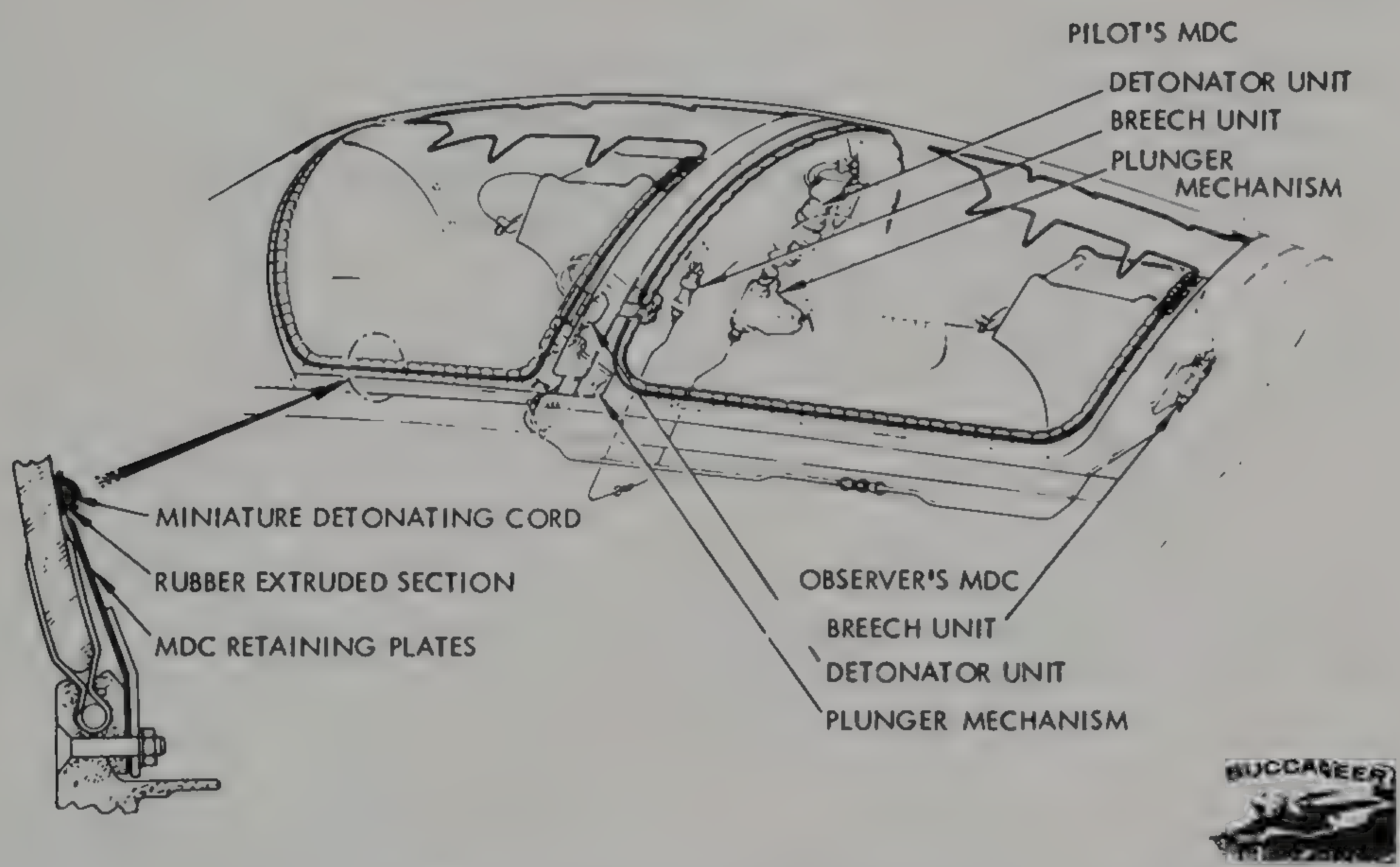
There was a worry on the Buccaneer that ditching with canopy off could rapidly fill the cockpit with water, cause the nose to sink rapidly, and cause compressive drowning of the occupants, the incident with XK 529 being particularly relevant. It was therefore decided to investigate underwater escape through the canopy. Use was made of the test facilities at HMS *Vernon* (Portsmouth) and at Glen Fruin, with ejection of dummies and some live subjects. There emerged a worry in that the initial small hole punched by the headbreakers could lead to a violent inrush of water under pressure sufficient to break the subject's neck before the ejection sequence had progressed sufficiently. The idea was mooted for using a plastic explosive strip — now known as MDC, miniature detonating cord — to fragment the canopy sufficiently to avoid this problem. Work then started to develop this for the underwater case.

With this work in progress, in February 1966, with the rocket-assisted seat maturing, I saw the prospect of a near-revolution in escape systems. With the true zero-zero capability of the rocket-assisted seat, escape prior to ditching would be completely practicable, even in the small time available from catapulting failure or going over the side of the ship. Timing in such cases would necessitate ejecting through the canopy. If miniature detonating cord could fragment the canopy in a manner satisfactory for the underwater case, the same should be possible for the airborne and on-the-ground cases. In the limit, both underwater and canopy jettison systems could be eliminated, but as a first step ejection through the canopy could be made much less hazardous.

Means of mounting the MDC on to the canopy, and methods of initiating its firing, had to be studied in the first instance. With a solution to this reached,

work began at Brough on break-up patterns. At first a peripheral pattern was used to quite good effect, although the fragmented pieces were in some cases of a size to constitute a danger. The final solution was a wavy pattern MDC over the surface of the canopy, developed to give the best crack initiation for an acceptable break-up pattern while not creating an unacceptable degradation of view from the cockpit. This arrangement became the standard aircrew escape system on the Buccaneer. Denavalization for service with the Royal Air Force led to the removal of the underwater compressed-air escape system, but the separate gas-powered canopy jettison system has remained.

The use of MDC as part of the basic escape mode of ejecting through the canopy, as developed for the Buccaneer, was to be adopted for several later aircraft types using the expertise developed by the staff at Brough. Harrier, Hawk



Miniature detonating cord system.

and, to some extent, the Tornado are typical examples, although a good deal more research was necessary for some of the applications. The transparency on the Buccaneer was of cast acrylic material. Later types used stretched acrylic, fragmentation of which is more difficult, but the problems were solved. The even later polycarbonate materials posed even greater problems, which have been tackled by the appropriate research programmes.

From this it can be seen that the Buccaneer proved to be a benchmark in the development of modern escape systems. Throughout the programme of aircrew escape development, a very close liaison was maintained with Martin-Baker Aircraft. Any significant development with them required the personal agreement of Sir James Martin — and what a character he was! His standards of engineering were of the highest, very little short of perfection got past him. He maintained a personal interest in the case of every aviator who had ejected using his equipment, and could quote statistics galore on them. He retained an aver-

sion to all influence from the various Ministries; with an independence which is rare these days, he either did his own thing or did someone else's thing his way.

Dealing with Sir James was an art in itself, and very few people could do it successfully. If one was to have a private meeting, one would arrive in his office at say 10.00 am, be hospitably received and treated to a session of Sir James in his role of raconteur. Lunchtime would arrive with one's programmed work not even started; a succulent lunch would be brought in for the visitors, while Sir James had an apple. When the remains had been cleared away, if we had not forgotten what we had come for, we could then get down to the business in hand. To the newcomer this procedure was frustrating, but one soon accepted it; and it must be said that the morning was usually both enjoyable and very informative. Sir James always admired survivors. Thus, if one retained one's wits and presented a case which, possibly after some argument, reached his agreement, a deal was firmly struck and speedy follow-up action would be ensured.

His ploy for large meetings, which usually involved significant Ministry participation and took place in a large cinema-type room with Sir James sitting centre-front at a desk, was never truly fathomed, although we felt certain of the system used. Whenever he looked like being defeated, or he had clearly had enough, was it coincidence that he was summoned from the room to attend to a VIP or was there a panic button under the desk? For certain, with him gone, the meeting could make only limited progress.

To my good fortune, all my meetings with Sir James were cordial, although there was one occasion when, with one of his henchmen, we had been to view Sir James' scheme for attaching MDC to the canopy. To us the scheme was more suitable for a battleship than for an aircraft, and was so far removed from our ideas that no agreed compromise seemed possible. Suddenly Sir James appeared in the distance, and the Keystone Cops chase round the plant to avoid a confrontation is an episode I shall never forget.

In later days Sir James involved himself directly rather less, leaving more to his henchmen, which included his son, but he still saw that his will and his rules were followed. In this period we had arranged for a Martin-Baker team to visit Brough to discuss our proposals for an articulating seat for the lightweight fighter. The names of the team were known beforehand, but when they arrived by air at about 9.45 am, to our surprise out stepped Sir James himself. With the rest of the party conducted to the conference room, I took Sir James into my office for a few preliminary words. There more surprise was to follow, when he asked if I could find him a bit of breakfast. Not to be beaten I did just that, but while we waited we chatted away in the course of which he used a ploy he had used many times saying, 'I'm a bit deaf you know', to which I replied 'Yes I know, you are when you want to be'. He just turned towards me and gave me a boyish grin.

Up to the beginning of the meeting Martin-Baker had rather discounted the idea of the articulating seat, and we were expecting a difficult morning. However, the presentation must have been convincing for, at the end, Sir James turned to his team and said, 'Give them what they want'. Unfortunately, not only was that the last time I saw him, but also neither the lightweight fighter nor the associated articulated seat ever saw the light of day.

Initial CA Release onwards

700Z Flight, having commenced operations with its development batch Buccaneers, continued for a year when 801 Squadron of the Fleet Air Arm became the first operational Buccaneer squadron with the early production S.1 aircraft. An intensive modification programme was activated to bring the aircraft of this squadron up to the standard which the development trials had shown to be desirable. This was done in time for the squadron to embark on HMS *Ark Royal*, and later on HMS *Victorious*, for overseas duty. The first commanding officer of this unit was Lt-Cdr E. R. (later Admiral Sir Edward) Anson, who had for a time been attached to the Blackburn flight-test organization as a test pilot, and later Senior Pilot of 700Z Flight. 801 Sqn was to continue on operations until July 1965, when it was disbanded, to be recommissioned with the Buccaneer S.2

700Z Flight was absorbed into 809 Squadron when it formed in January 1963, which, with its S.1 aircraft, continued to be shore-based at Lossiemouth. The final Buccaneer Mk 1 squadron, No 800, commissioned in March 1964, embarking on HMS *Eagle* in December of that year. By 1965 the Spey-engined Buccaneer S.2 was becoming available to replace the Mk 1 in recommissioned squadrons bearing the same numbers.

Continuing flight trials from July 1961 produced clearances for the autopilot by September 1962 and the full weapons system by October 1963. Compared with the initial plans drawn up before first flight in 1958, initial release was ten months late and full weapons system nearly two years later than targeted. Bearing in mind the giant step-forward which was involved, this was not a bad achievement.

One further statistic comes to mind. The initial flying shells, XK 486, 487 and 488, were built to 4,000 drawings. The final development aircraft, XK 524 onwards, were built to 9,000 drawings. Early production aircraft needed 12,000, which later with the S.2 increased to 15,000.

Expect the Unexpected

At the time of negotiations for the initial CA Release we had got impatient with the Engineering Division at Boscombe Down, especially at their reluctance to clear the flap-blowing system, inventing possible failures which we considered to be quite inappropriate. Total failure of the system would be catastrophic when embarked on a carrier but should be acceptable for most airfield operations. The careful detail engineering of the system made the probability of total failure exceedingly remote.

The blowing system was controlled by butterfly valves, which were operated by a pneumatic servo for which air was tapped from the duct just upstream of the butterfly itself. The servo ram moved in a chamber which, for operation in one direction, was vented to atmosphere by two solenoid-operated valves, each of which was connected to a different electrical system. At the time that the valve was developed, no air supply was available which could give maximum flow through the valve and also operate the servo, so each was tested and calibrated separately.

It hadn't happened before, and it never happened again, but, within ten minutes of each other, two pilots in the circuit reported an apparently impossible

blow failure. By this time the compressed-air reservoirs for the Brough high-speed wind tunnel could give an adequate supply of air to enable the complete valve and servo to be tested together. It emerged that, with one electrical system failed, and hence only one of the solenoid-operated valves working, operation of the butterfly valve was decidedly sluggish, In a condition of the aircraft of relatively low engine rpm, and hence low bleed air pressure, this sluggishness would be increased. What had not been realised was that the butterfly valve in an intermediate position, early in its sweep, would at about its maximum hinge-moment position pass the bleed hole for the sevo actuating air. With the sluggishness already referred to, the butterfly moved slowly and, blocking off the air for the servo as it staggered past the bleed hole, brought itself to a standstill! A condition such as this would align with the reported troubles in the air. With the knowledge gained, modification action was relatively easy, but it took a great deal to convince the authorities that we had diagnosed the trouble and remedied it. The two pilots involved with this incident were later to be entered into our 'book of fame', one for a series of self-induced mishaps and the other for being subject to the most incredible multiple-failure situation.

In the course of the operation of the Buccaneer S.1 at Lossiemouth there occurred a series of failures of part of the main undercarriage mechanism which appeared to defy explanation. Almost invariably they occurred during flying on a Friday afternoon. They would result in an immediate panic call to Brough for assistance, leaving me to round up one of two experts and despatch him on the sleeper from York to Inverness, with his week-end ruined.

The main undercarriage leg contained a device which pulled the wheel assembly upwards, close to the leg, to reduce stowage requirements, known as the shortening mechanism. It was the attachment of this mechanism to the main airframe which was failing, with the result that the wheel moved up into the stowed position with resultant damage to undercarriage doors and anything else which happened to be below the new clearance line. After several incidents and looking at the damage, I came to the conclusion that the cause must be some applied side-load, but I was assured by the experts that this could not be so, as the design specifically prevented any side-load being transmitted into the links. Without going into details, this was effected by driving a knuckle joint over dead centre, and resting it against an abutment.

After a series of rigorous tests on an undercarriage it was found that side-load on its own had no effect. On the other hand, if more than a certain critical degree of backlash existed in the shortening mechanism, side-load plus a vertical load could cause the knuckle joint to come away from the abutment. Thus a different load path was created, which would lead to the type of failure being investigated. Accordingly the degree of over-dead-centre of the knuckle joint was increased by a factor of four, and the source of these troublesome failures successfully removed. This story is a good example of the blockage which can occur in a designer's mind, in line with the assumptions which he made in the first instance. Equally, my instinctive or logical deduction that the cause of these failures must be side-load did not in any way anticipate the improbable means by which it was found to be transmitted.

And so to the story of the incredible series of multiple failures which hit XN 967 at Lossiemouth on 27 November 1965. The pilot, Lt Bill Rice, had been responsible for putting pilots under training through failure drills on the

simulator. He was also making what was probably his last flight in a Buccaneer S.1 before leaving the Service. If his students had tried to fix him, they couldn't have made a better job of it.

The aircraft took off with full internal and wing drop tanks. Undercarriage up selection was followed by three reds and then no lights — a perfectly normal sequence. Almost immediately, the air-turbine alternator failed, but the standby inverter did not take over. As a result, Rice abandoned the sortie and, as the first step of returning to base, selected undercarriage down. This resulted in a loud bang, and some 15 seconds of rumbling. No undercarriage lights illuminated, so an emergency-down selection was made with no apparent effect. Normal down was then reselected, but the system indicator remained showing 'emergency'.

Fuel jettison was now selected, and at this time was observed to be working, although no further observations were made. Selection of flaps down and of airbrake had no effect. Aileron droop and blow, which were electrically rather than hydraulically operated, were selected and obtained. The canopy was jettisoned, and the aircraft then landed when, due to the failure of the shortening mechanism, the port undercarriage collapsed and the aircraft slewed off the runway onto the grass.

Observations made after the aircraft had been recovered into the hangar included: The nosewheel had slewed over before retracting, and had jammed up against the underside of the fuselage, the port main undercarriage had suffered two failures, one being the failure of the attachment of the retraction jack to the airframe and the other the failure of the shortening mechanism, damage in the port wheel bay included the 'undercarriage-locked' microswitch, and severed pipes of normal and emergency undercarriage hydraulic circuits. A pipe of the port flying-control hydraulic system was also severed. Both general-services hydraulic systems had drained dry, and the port flying-control system was approaching that state. Various other failures reported could all be explained by the above. Fuel remaining showed that fuel jettison had worked for only about one minute of the five minutes for which it was selected, and this gives an indication of when the general-services hydraulic system became drained.

Following a request for assistance, I arrived at Lossiemouth accompanied by one of my undercarriage experts, Stan Field. At this point there were no indications regarding which were primary and which were secondary failures, with an inference that there was no connection between some of them. The only line to pursue was to plot known events on a time history basis, which we did, subsequently augmented from an air-traffic-control tape and some second thoughts from the pilot. After a struggle we managed to produce a coherent sequence.

The failure of the air-turbine alternator was not uncommon, but the failure of the 107 inverter to take over was due to a vent plug having become loose, falling into the control box across some terminals, and causing a short circuit! It was fortunate that at this stage the pilot decided to return to base, for, unbeknown to him at this stage, other failures had occurred which in a relatively short time would have placed him in extreme difficulty — to put it mildly.

The slewing of the nosewheel and its subsequent failure to retract was an independent failure, which would have been indicated to the pilot had the undercarriage-indication circuit not at this time been damaged in the port

mainwheel bay. With the normal and emergency-down hydraulic pipes severed, on down selection the port undercarriage ran away under air loads, breaking through the beak abutment which contained the spring-loaded downlock, pulling the retraction jack away from its mounting, and failing the shortening mechanism which then, in turn, severed the port system flying-control pipe. Air loading then caused the leg to centre, to allow the spring-loaded downlock to engage.

From the failure of the nosewheel to retract, and with the associated lack of indication, it was deduced that the damage to the microswitch and hydraulic pipes in the port mainwheel bay occurred during the retraction cycle. All subsequent events line up with this, with the hydraulic systems then draining away. The damage was consistent with a foreign object being trapped between the retracting leg and the forward edge of the bay, and there were scour marks on the leg to support this. The marks corresponded exactly to an open groundlock, which could have fallen off a ledge at the front of the bay. As the retraction took place over the sea no search was possible, and a tally at the station accounted for all known groundlocks. Thus the theory was never confirmed, but the series of dependent and independent failures experienced over a short period of 15 minutes must be unique, and certainly should not be considered in a design stage failure analysis.

These few incidents have been selected from memory to highlight the fact that in spite of the most meticulous design process, the unexpected is always liable to happen.

XK 532 as Gate Guardian at RAF Lossiemouth. *(MOD(RAF))*

Chapter 9
Buccaneer Mark 2 and Variants — Actual and Proposed

The Initial Mark 2

We had always been marginal on thrust, and proposals for re-engining the Buccaneer were receiving serious attention as early as 1959. On 12 January 1960 a meeting at Brough with senior representatives of the Ministry of Aviation and Royal Navy discussed three alternatives.

A proposal from de Havilland Engines (losing its identity in Bristol Siddeley) was for an aft-fan derivative of the Gyron Junior, giving a static thrust of 10,700 lb for a weight penalty of 1,800 lb. Early availability was offered, but, apart from severe installational difficulties, the increase in range obtainable was only 25 per cent.

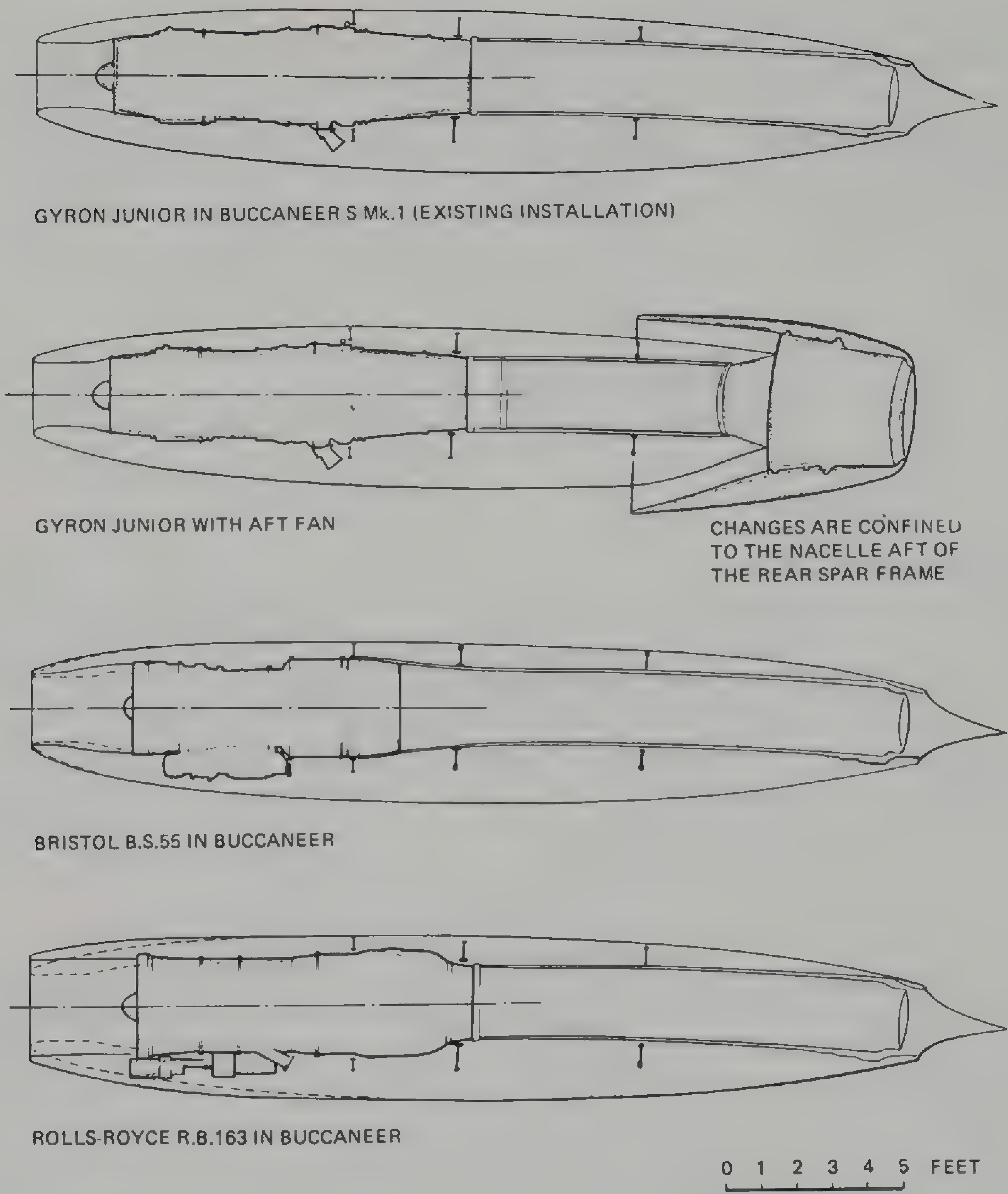
Bristol Siddeley offered the BS.55, a front-fan development of the Orpheus, giving 9,000 lb thrust, reducing to 8,340 lb with BLC bleed. Little was known of this proposition, timescale was uncertain, and improvement in range was 30 per cent.

The Rolls-Royce proposal was for a military version of the RB.163 Spey, which in its civil form was firmly committed to the Trident airliner. Thrust quoted was 11,380 lb, reducing to 9,600 lb with BLC air bleed and with a weight penalty of 1,100 lb. No major installational problems could be foreseen. In spite of an 80 per cent increase in mass flow, with careful tailoring of fire zones and ventilation, the jetpipe could be passed through the existing spar rings, and an average range increase of 80 per cent was predicted. There was little doubt that a Spey installation was the preferred course.

At this stage programme dates offered, including the conversion of two of the Mk 1 development batch aircraft were: start conversion, March 1961; first flight, December 1961; first production delivery, October 1963.

In fact, due to existing programme commitments, no development aircraft was available for conversion until January 1962. Conversion, including delivery of flight-cleared engines, took until May 1963, 16 months instead of the originally quoted nine. In spite of the ten-months-late start, and further six months delay in conversion of the prototypes, the first production delivery in June 1964 was only eight months later than the original date, and thereafter the programme ran to schedule.

For the discussions in January 1960, a paper was prepared which reviewed additional changes which might be considered. Strangely, there was no mention



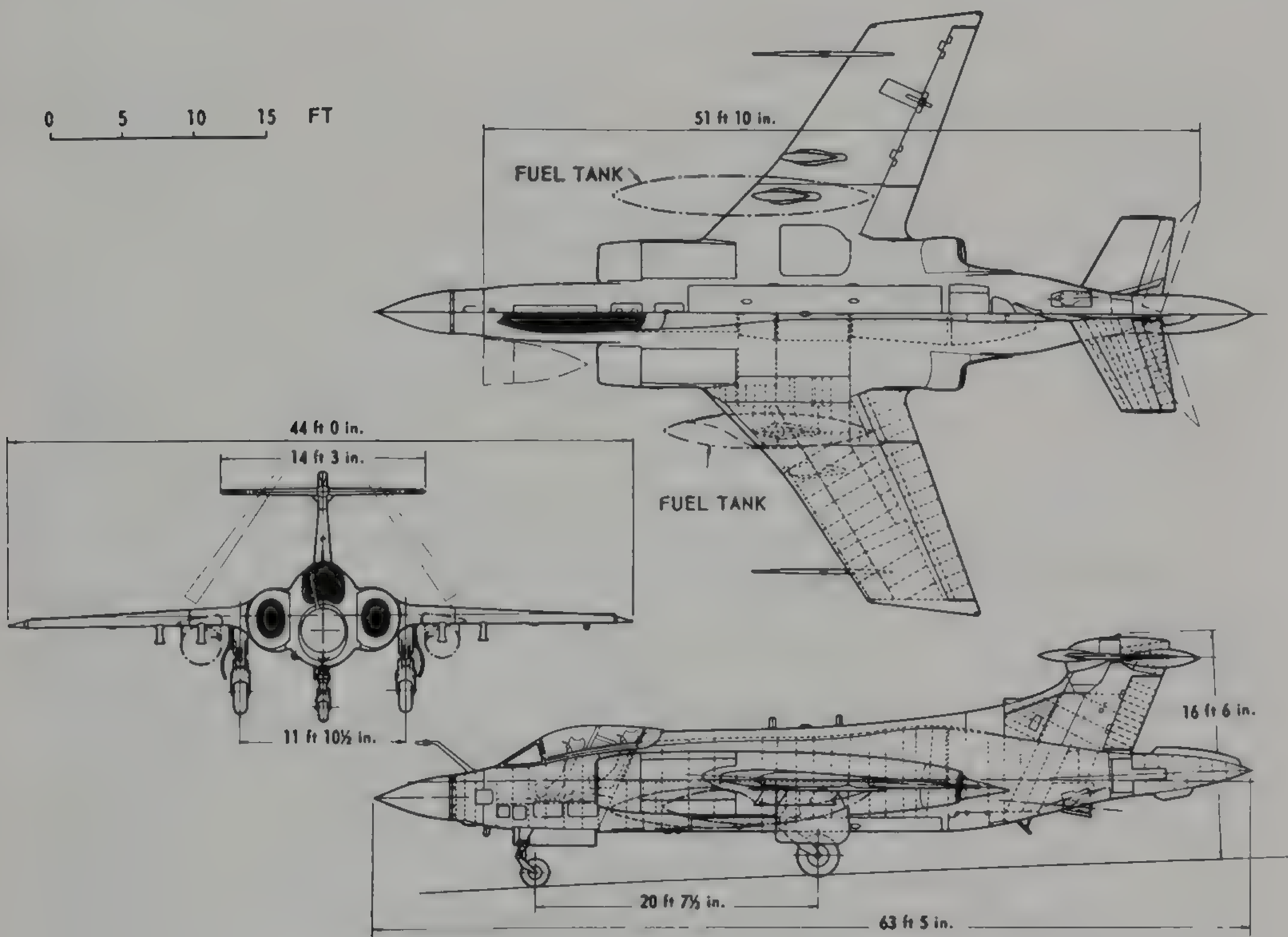
Line diagram of engine installations for the Buccaneer Mark 2.

of a new electrical generation system which, in fact, was to be included in the Mk 2. For the first time an inertial platform with Doppler mixing was proposed, with the rider that an English Electric-licensed Honeywell platform should be chosen, the Ferranti platform being in too early a stage of development.

Ground mapping and terrain-clearance modes were also discussed. Sideways-looking radar was ruled out, for, whilst the transmitter and aerials could be accommodated, the then state-of-the-art displays could not. Application of a radar trick known as monopulse resolution enhancement was thought to be the best approach for ground mapping. This was, in fact, adopted, but not until nine years later when the Buccaneer entered service with the Royal Air Force. A ground-position marker obtained from radar information was proposed for superimposing on the roller-map display, and a terrain-clearance mode for the Blue Parrot radar was suggested, although the radar would have to be specifically switched to this mode.

Proposals were also made for a force-sensing stick and electrically signalled flight-control system, and for a comprehensive electronic warfare and/or reconnaissance pack to fit into the bomb bay for alternative roles. The use of the Buccaneer as a fighter, possibly with reheated Speys, was also discussed, including anticipated sensor and weapon developments.

Thus a good deal of forward thinking was in train, but, at the time, only the change from Gyron Junior to Spey engines met with a positive response. Nevertheless, following the work done by English Electric at Bradford on constant-speed drives and alternators, there was a degree of support for the introduction of a new AC electrical generation system in various quarters.



General arrangements of the Buccaneer Marks 2 and 50.

From these discussions in January 1960 scheming of the structural changes to accommodate the Spey proceeded in earnest. Lines for the nacelle were drawn up with an enlarged elliptical intake, and with the jetpipe canted downwards and outwards which, with a compound angle, avoided handing the port and starboard pipes. At an early stage it became apparent that the original idea of engine mounting similar to that on the Mk 1 was incompatible with the Spey engine as built, and that much more extensive changes would have to be introduced into the centre fuselage to take the Spey. Nevertheless, these changes were taken in our stride.

The Spey is a two-spool bypass engine with HP bleeds at significantly higher pressures and temperatures than came off the rear of the Gyron Junior. The difference would be embarrassing for the ducting of the Buccaneer air-bleed

system. The solution was to bleed from the seventh HP stage, with a limited tapping of very hot 12th-stage air for specific purposes. This was to cause a minor hiccup in the programme later on.

The work towards the Buccaneer Mk 2 had reached this stage when, in July 1961, immediately following the initial entry of the S.1 into service, I moved back from Holme on Spalding Moor to Brough to take charge of the Mk 2 programme. Structural design work was well in hand, the engine change on its own had been authorized, and interim financial cover given pending negotiations for a full contract. The tenth and eleventh development-batch aircraft, XK 526 and 527, were to be converted as prototypes, and it was proposed to switch the last ten of the current Mk 1 production order to become the initial production Mk 2s.

The main tasks at that time were to sort out the agreed activities into an organized programme, prepare the estimates, and assist in the contract negotiations. Having done that, the situation was ripe to consider what additional changes could be included in the transition from Mk 1 to Mk 2.

The existing cost estimates for the prototype conversion appeared to be sound, but the figures for the production aircraft design seemed to me to be grossly under-estimated. With my own ideas of what they should be, I sent the experts off to reconsider. When they returned with unchanged figures there was a problem. In the event, I simply doubled all their figures. Needless to say, two years later I was negotiating cover for a 33 per cent increase on the doubled figures.

During this mayhem the Brough Contracts Manager died very suddenly, and it was obvious that the Mk 2 contract negotiations would have to be completed before his replacement could be appointed. I therefore found myself more heavily involved on the subject than expected, added to which was the uncertainty of the effective start date. XK 526, the first of the two aircraft for conversion had completed its tropical trials in August 1961, but was stranded at Singapore awaiting shipment home, with no firm date for this available. It looked that, at best, a three-month delay was to be incurred.

This turned out to be a blessing in disguise. Only too well aware of the shortcomings of the Mk 1 electrical generation system, I was anxious to include the two constant-speed drives and 30-kVA alternators in the programme. Nothing seemed to be moving on this, so I hastened down to the Admiralty to see Captain Parker, then Director of Naval Air Warfare. I found him relaxed over the AC system, in the belief that it could be added at a later date. I pointed out that the engine gearbox would be quite different and the engine/gearbox combination would require a full programme of development and type testing, and I couldn't see the work being covered twice. Captain Parker reacted immediately, and managed to obtain full approval for the new AC system change to be included in the conversion. Without the three-month delay which we had been enforced to suffer, it is doubtful if the administrative work to include this important change could have been managed.

It was at this time that I paid my first liaison visit visit to Rolls-Royce at Derby. I told Ernest Eltis of the three-month delay which we were putting into the programme. He was furious, and set about me, saying how well Rolls-Royce had progressed, largely with their own money. With the experience of the Mk 1 behind me, I asked Ernest if they had run the Spey at full power with the

specified air-bleed offtake. The answer was in the negative, so I said that, when they had done this successfully, if we were then holding the job up, he could have my guts for garters.

Jumping forward in time, when they were due for fitment to the aircraft, while some engines came off test satisfactorily, several failed for reasons which were not understood, and there was indeed a hiccup in the programme. Eventually it was discovered that, due to flow irregularities through the later compressor stages caused by the air-bleed offtake at the seventh stage, there was a critical value of blade torsional frequency, beyond which blades failed. Selective assembly was made as an interim solution, and a regular supply of engines resumed. The situation while it lasted certainly gave us some headaches. However if Ernest remembered our earlier conversation, it had saved me from mutilation.

Returning now to the winter 1961-62, we had an agreed programme for the change of engine and electrical generation system, XK 526 was finally on conversion, and XK 527 was programmed to follow at the required interval.

It was at this point that the three years of operating S.1 aircraft had its influence. Many of the delays experienced had been due to unserviceable microswitches and relays. More reliable equipment was now readily available, and in use on civil aircraft. With a sympathetic Project Officer at the Ministry, we agreed to change the offending components. Additionally, anticipating operation at higher weights than had been the norm with the Mk 1, we also agreed to fit higher-capacity wheels and brakes, which had by then become available. Time has proved these decisions to have been a good move, for reliability increased enormously, but in the immediate pre-flight days a further crisis arose. Many of the new components which we had fitted, whilst coming from a proven background in civil operation, did not carry with them the Form 100A clearance essential if the aircraft was to be cleared for flight in the normal way. We had anticipated this problem, but progress in obtaining the necessary documentation from the suppliers was lagging far behind our needs, and it required quite an effort to get the process speeded up in time to meet the programme.

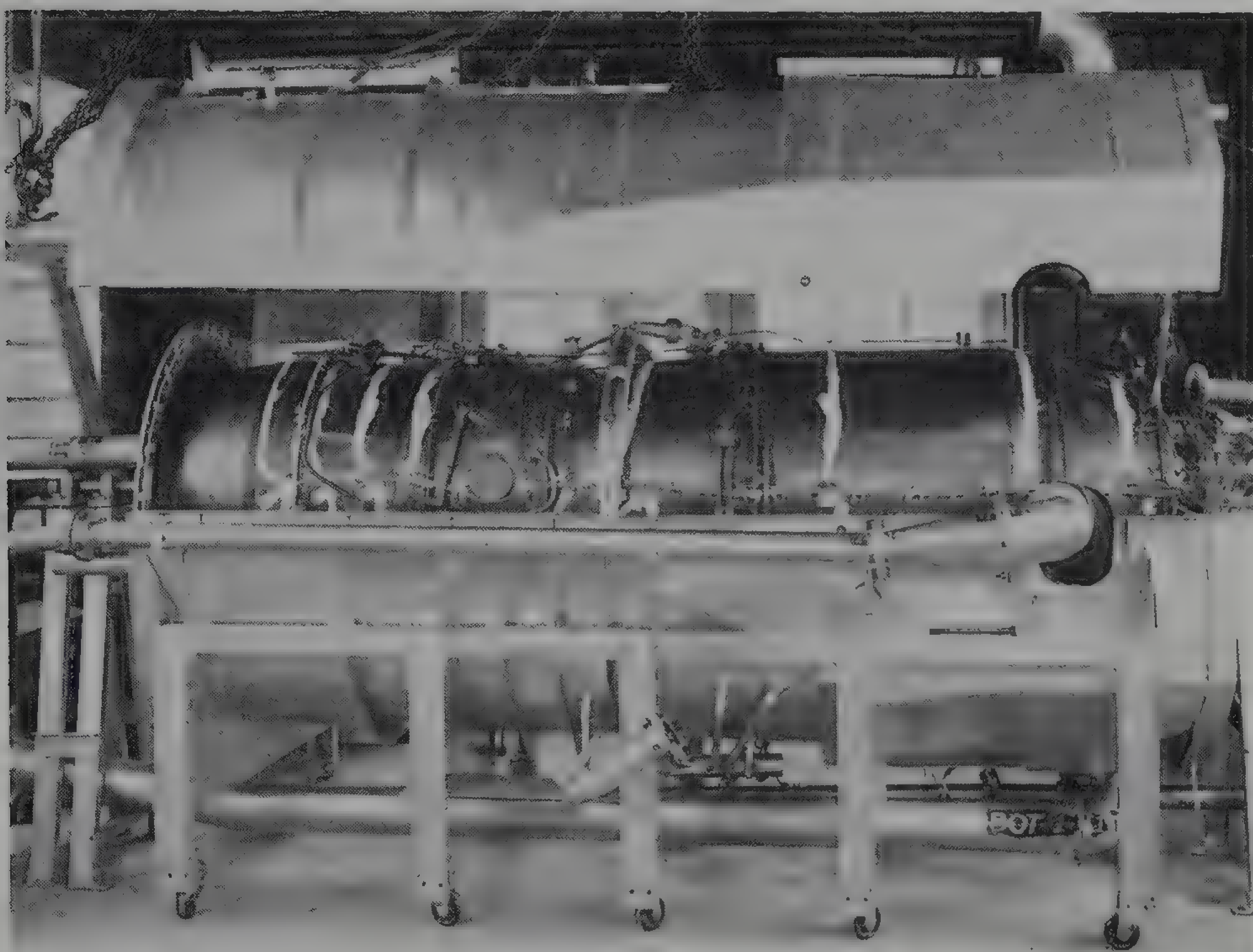
Unfortunately this was not the only matter to crop up to impede the clearance for flight. The area around the engine is always prone to leaks of fuel and/or hydraulic fluid, with an associated fire risk arising from spontaneous combustion. The Good Book (AvP.970) stipulated that temperatures in such zones should not exceed 200°C. Rolls-Royce had done a lot of research and test work on this subject, and had demonstrated that, with a prescribed degree of ventilation through the bay, a temperature of 400°C was perfectly safe. On recommendations from Rolls-Royce on this matter, the Buccaneer Mk 2 engine installation was designed with the appropriate degree of ventilation and maximum temperature in the upper 300°C range. When the time came, RDI Fires, the approving branch from the Ministry, refused to clear the installation for flight, on the grounds of non-compliance with AvP.970. The situation was serious, as there was no room for lagging or other means of bringing the bay temperatures down to the stipulated level. We had to call in one of the Directors from the Ministry to chair a meeting at which Rolls-Royce presented their work. He appeared to be convinced of its validity, but required us to construct a fire tunnel and, with the actual Buccaneer installation, demonstrate an acceptable

XK 526 takes off on the first flight of a Mark 2 prototype, 17 May 1963. *(BAL 19397)*

A Mark 1 and Mark 2 Buccaneer in formation, June 1964. *(BAL 20027)*

situation. This was done and in the end all was well, not to mention the fact that Brough now had an additional and very useful test facility, which has been put to good use in succeeding years.

On the whole, the conversion programme went very well. A few more improvements were introduced, based on Mk 1 experience, and XK 526 took to the air on 17 May 1963. It did a tight turn immediately after takeoff, followed by a fast fly-past over the airfield, and the Mk 2 test programme was underway.

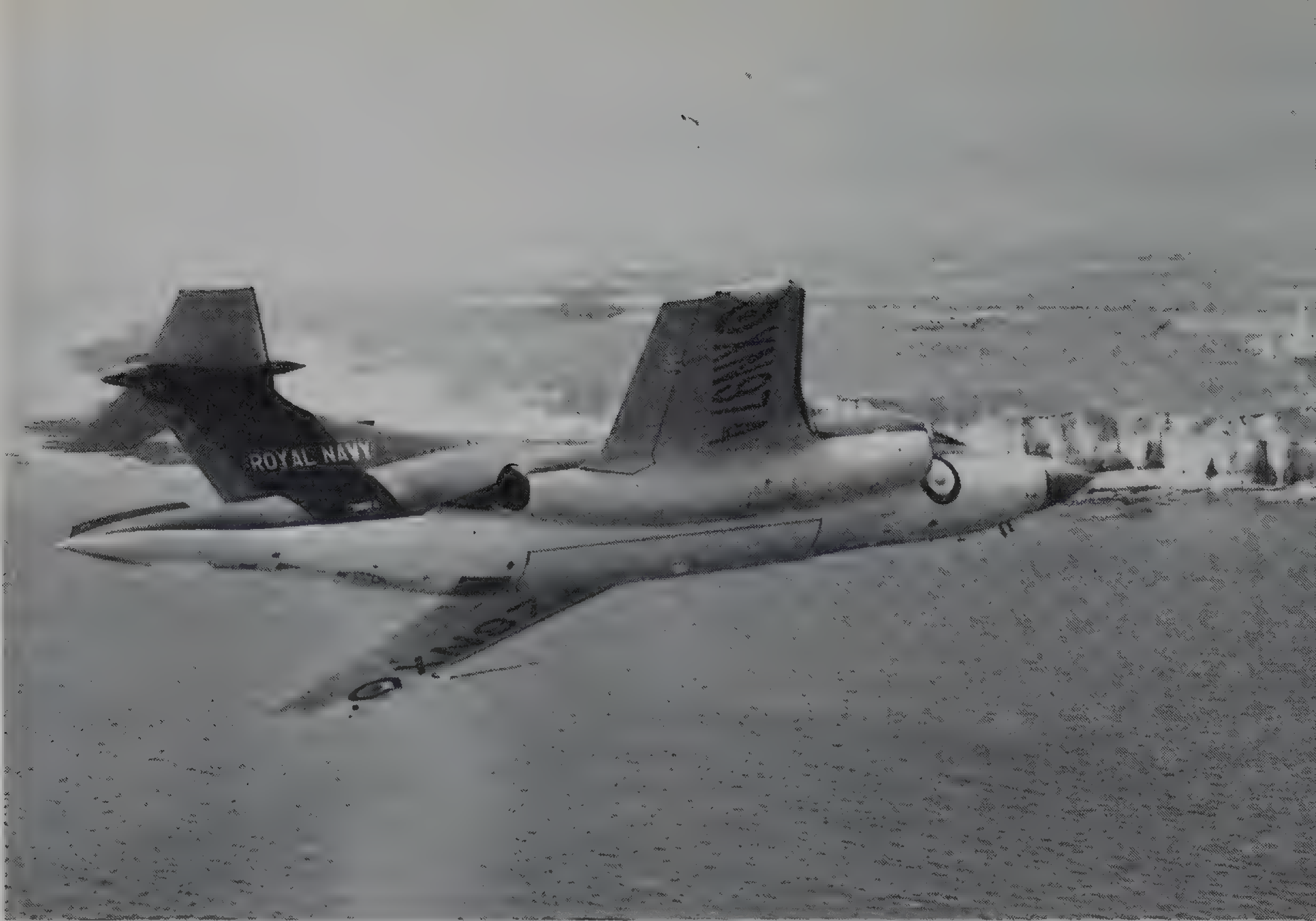


The Brough fire tunnel (open).

In the meantime, the Works Director, having seen the changes involved and with Mk 1 centre fuselages under construction in their jigs, asked if we could produce a repair scheme to turn them into Mk 2s, and thus give him some additional lead into his programme. This we did, and it was probably this initiative which enabled production aircraft to follow the first prototype in 13 months, rather than the originally predicted 22 months.

The second prototype, XK 527, followed XK 526 to fly in September 1963 and to be joined on the clearance programme by the first three production aircraft, XN 974, 975 and 976, with first flights in June, July and August 1964, respectively. There was a great deal of work to be done on the programme as much of the handling, flutter and performance already done for the Mk 1 had to be repeated, in addition to covering the entirely new features.

One of the surprises emanating from the programme was the level of aerodynamically excited noise in the cockpit at the higher speeds, the Mk 1 at these speeds having been sufficiently quiet to escape mention. The source had to be the influence of the revised nacelle at the bodyside. A number of fairings from abeam of the cockpit aft to the nacelle/fuselage intersection were tested, and one



XN 974 over Flamborough Head, June 1964. Note the camera pods on the wing tips for observing stores separation. *(BAL 19991/9)*

A Buccaneer Mark 1 buddy refuelling from a Mark 2 aircraft, April 1965. *(BAL 20828)*

in particular brought the noise level down to the desired value. It did, however, cause a redistribution of pressure across the engine face, which Rolls-Royce considered to be unacceptable due to a possible reduction in fatigue life. A modified fairing plus some soundproofing insulation on the inside of the cockpit was adopted as the best compromise solution, but at maximum speed the resulting noise level is still greater than one would like.

It became obvious at an early stage of testing that excessive drag was being incurred during cruise. With the knowledge of the VC 10 problems stored in my mind, in the same way that I had looked at the fin/tailplane junction, I stood in the hangar near the rear of XK 527 looking forward over the nacelles. With the downwards and outwards deflection of the jetpipes, one could see the excessive expansion between the rear nacelle and fuselage, and also a large base area from which the jetpipe cooling air emerged. Some swift redesign action reduced the base area and introduced new rear nacelle lines, the latter not being achieved without a major problem of getting an acceptable shape without causing the jetpipes to be handed, the minimum degree of downward deflection being defined by the position of the open airbrakes.

These modifications, during the course of which I was christened 'Lord Nacelles' in the Drawing Office were largely successful, but cruising performance at high altitude was still giving cause for concern. Of course we blamed the engine but, unlike the situation on the Mk 1, there was now at Derby a High-Altitude Test Facility. With some results available, a meeting took place at Brough chaired for the Ministry by Laurie Stern. As the Rolls-Royce representative resisted any suggestions whatsoever for changes to the engine, Laurie interjected with "You remind me of Oscar Wilde who, when some changes to his play were suggested during rehearsals, humbly denied being an adequate person to alter a masterpiece." In the end some improvements to the engine and the airframe-associated engine control system were agreed, and had limited success.

To improve the high-altitude cruising performance further, the square-cut wing tips were replaced with triangular ones, which increased span without encroaching on wing folding clearance limits in the aircraft-carrier hangar. This did give a worthwhile improvement, and checks made at the time on the possible effect on overall strength of the wing showed it to be negligible. Sadly, many years later, following a catastrophic failure of the main front spar, a critical local stress which had not previously been detected was found. The decision was taken to remove these extended tips, and to revert to the original square-cut ones.

The flight programme went very well, in time for the Royal Navy Intensive Flying Trials Unit, this time 700B, to form in April 1965. With a strength rising to eight aircraft the IFTU accomplished its alloted task by the end of September, and disbanded in time for the commissioning of 801 Squadron on 14 October 1965. At the commissioning ceremony held at Lossiemouth the Admiral conducting the ceremony caused much hilarity by welcoming the Barracuda Mk 2.

Other units followed in rapid succession, No 809 commissioned in January 1966, to embark on HMS *Hermes* in 1967, 800 followed later that year, scheduled for HMS *Eagle*, with 803 forming in 1967. In addition, in 1966, 736 Sqn was formed as a land-based headquarters and training unit, initially with S.1 aircraft from the previous commissions on 801 and 809, to be supplemented by

Two Buccaneers flight refuelling from a Victor tanker, 1968. *(BAL 23561)*

Ready for catapulting from HMS *Hermes*, July 1966. *(L 2720)*

Deck landing on HMS *Hermes*. July 1966. *(L 2719)*

Buccaneer XV 350 with four Martel missiles. *(BL 23941)*

some S.2 aircraft at a later date. This unit continued in operation until February 1972, by which time the training function had been taken over entirely by 237 OCU of the Royal Air Force.

The entry into service of the S.2 in April 1965 was by no means the end of the flight-development programme. Apart from completing the basic clearance of the type, this has encompassed changes in equipment and armament continuing up to today.

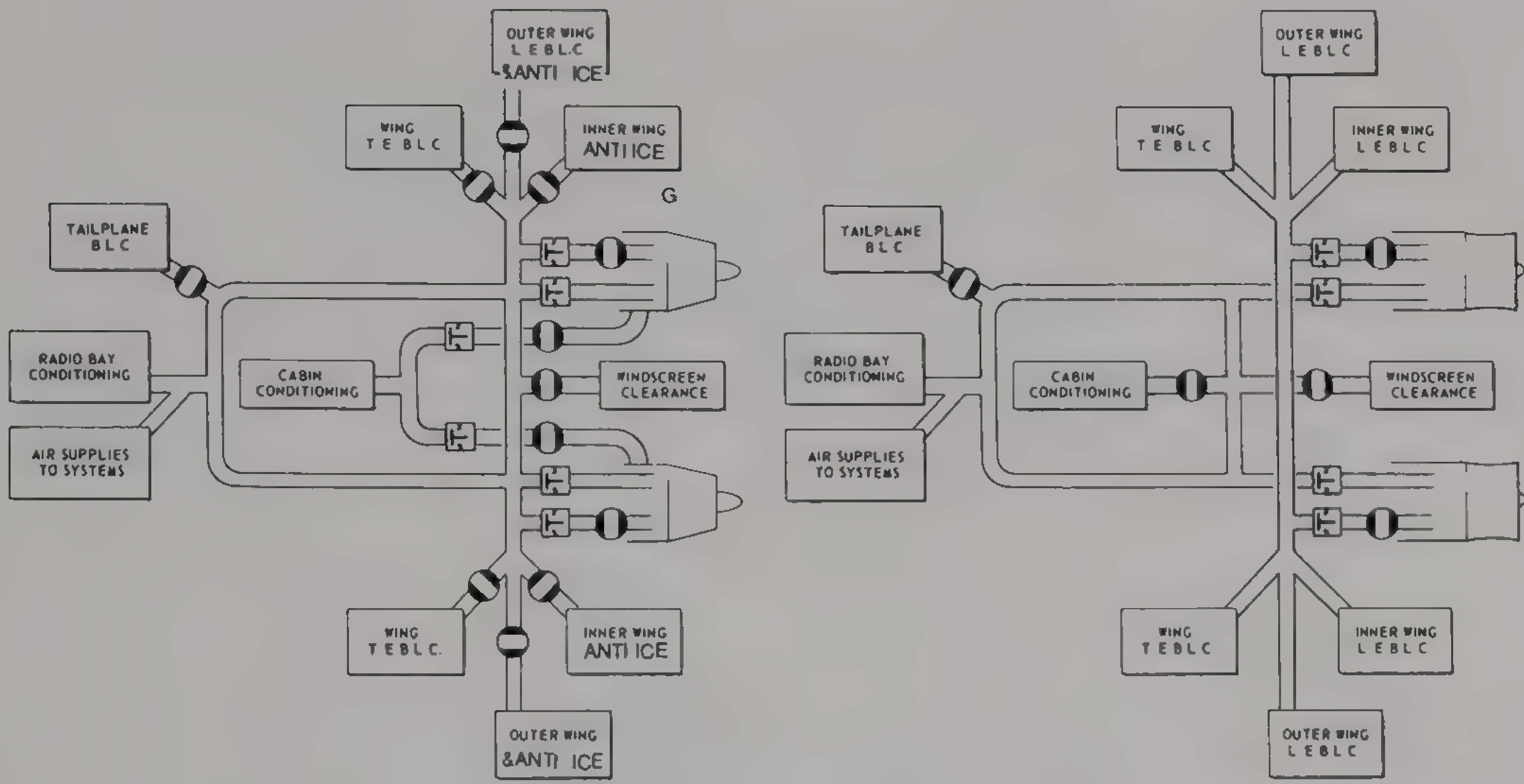
One incident during the basic clearance which stands out is when XK 527 was engaged on roll/inertia coupling tests with external stores, with Paul Millett as pilot. Starting the test at high altitude, Paul found the aircraft to be entering into a spin. Taking recovery action, he regained control many thousands of feet lower. Trace records showed that both engines were on the point of flaming out — a situation which we had always feared. This incident is the only one known where a Buccaneer has entered a spin and not been lost.

Because of the ongoing nature of the Mk 2 programme it cannot be summarised as succinctly as the Mk 1. Indeed some of it has been associated with the introduction of variants, which will be related separately.

There was a series of carrier trials, which not only gave the initial operating clearance but extended it, either with improved launch and/or arresting speeds or in different stores configurations. The first of these was in HMS *Eagle* in September 1964, with XN 974 for a preliminary look. This was followed by main trials on HMS *Ark Royal* in March 1965, when a programme for 100 launches taking two weeks was completed with 78 launches within one week. In October 1965 three aircraft, XK 527, XN 974 and 976 were based in Florida for hot-weather trials, two of them made some 100 launches from USS *Lexington*. XN 974 then distinguished itself by flying non-stop without flight refuelling from Goose Bay to Lossiemouth, 1950 miles, piloted by Commander Geoff Higgs. The trials continued on HMS *Hermes* in July 1966, again in September 1966 for night-flying clearance, and in November 1966 and March 1967.

A further trial took place in June 1968, in connection with a wing drop tank problem which had arisen. One of the improvements which I had introduced on the Mk 2 was in the boundary-layer control system. Feeling that the complication of the anti-icing mode was unnecessary, I argued that the aircraft would either be going fast enough to avoid the problem or at lower speeds, could have BLC switched on, which would heat the leading edges to the necessary temperature. On the Mk 1 the inner-wing leading edge had an anti-icing installation, but no BLC. To help offset the MK 2s 2,000 lb weight increase, lift augmentation on the inner wing would be helpful and was practicable, so a new leading-edge duct was made. The changes to the system eliminated all valves in the wing, and the slit on the tailplane was brought forward from 5 per cent chord, as originally positioned for anti-icing, to 2 per cent which was more optimum for high lift.

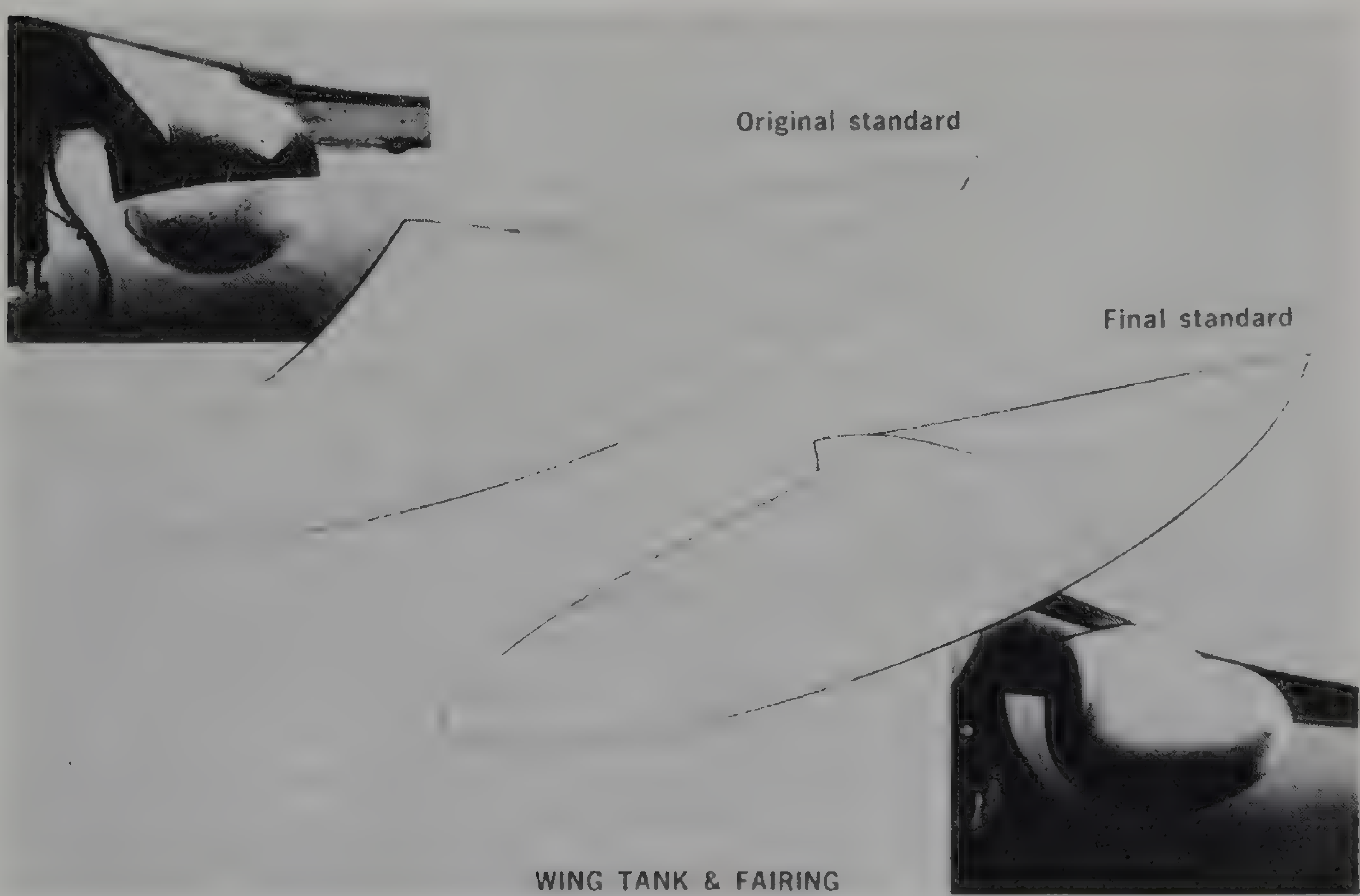
On 9 June 1966 XN 979 launched from HMS *Victorious* and immediately crashed into the sea. No explanation was forthcoming and, following the success of the preceding trials, A&AEE were convinced that piloting technique was at fault. They sent one of their pilots, Lt-Cdr David Eagles, to demonstrate. His first flight of this assignment lasted less than 20 seconds, which clearly showed that there was a problem. Eventually a fix was found by changing the shape of the fairing between the wing tank and the leading edge. A further trial took place on HMS *Hermes* in June 1968 to clear the revised tank. Its new fairing



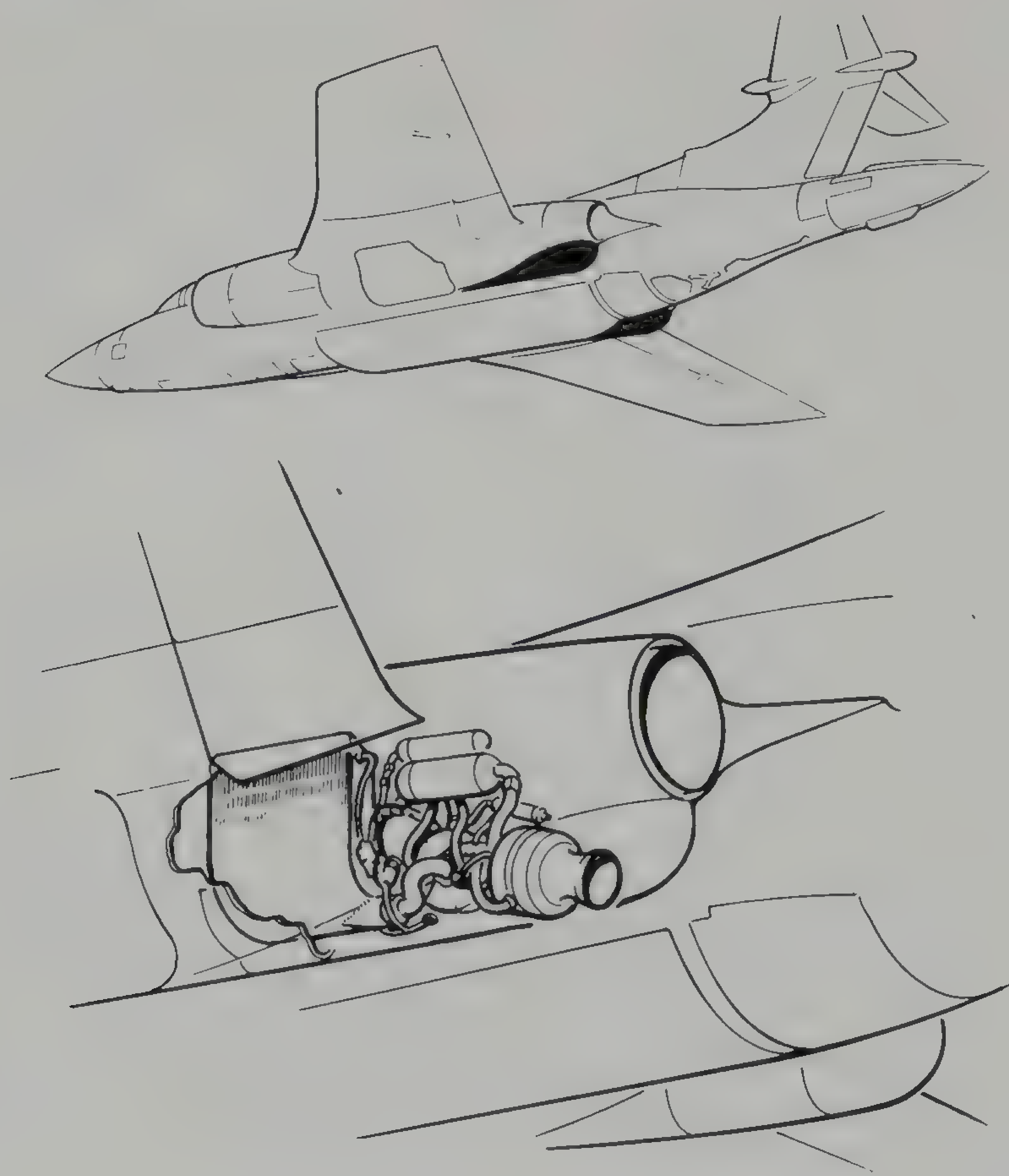
The Buccaneer Mark 1 and Mark 2 Air Bleed Systems.

gave slightly more drag than the original shape, but was more compatible with the flow over the wing with inner-wing blowing. When the Royal Air Force took over the Buccaneers, having no critical post-catapult-launch condition to cope with, they reverted to the original lower-drag configuration.

The Buccaneer Mk 2, apart from its vastly improved performance, showed a large increase in reliability, some of which was undoubtedly due to the secondary improvements which we had fed into it. It is still giving a good account of itself 24 years after it went into service.



Buccaneer wing tanks.



Buccaneer nacelle rocket installation.

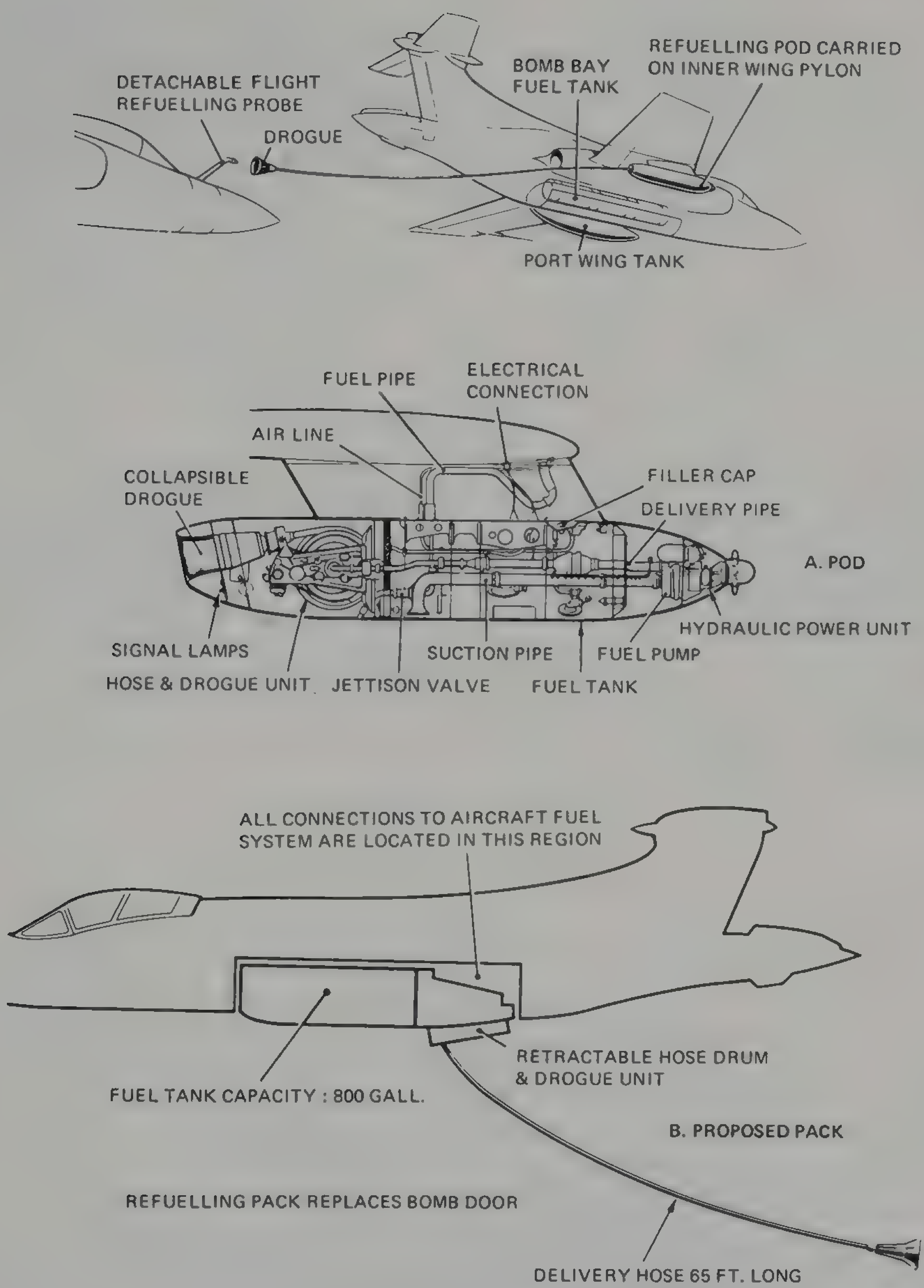
Buccaneer Mark 50 (B.136) for South Africa

In mid-1962, well before the Buccaneer Mk 2 had flown, following discussions in South Africa, proposals were prepared for a version of the Buccaneer to meet the requirements of the South African Air Force. (At that time Britain had normal commercial and defence relations with that country.)

Two major changes from the Mk 2 were to provide wing drop tanks of 430 gallons capacity (some 70 per cent more than those in service with the Royal Navy) and a rocket installation to increase takeoff thrust. The latter was mainly to counter the hot and high conditions at airfields from which the aircraft would be required to operate, but also to take account of higher takeoff weights which were proposed for this version, which could be up to 58,000 lb.

The rocket unit selected was the Bristol Siddeley BS.605, two of which were to be fitted, in the first proposal in the rear of each nacelle under the main jet pipe. These units used high-test hydrogen peroxide (HTP) as oxidant in conjunction with kerosene fuel drawn from the aircraft main supply. Each rocket gave 4,000 lb thrust for 30 seconds, during which time they used a total of 1,100 lb of HTP.

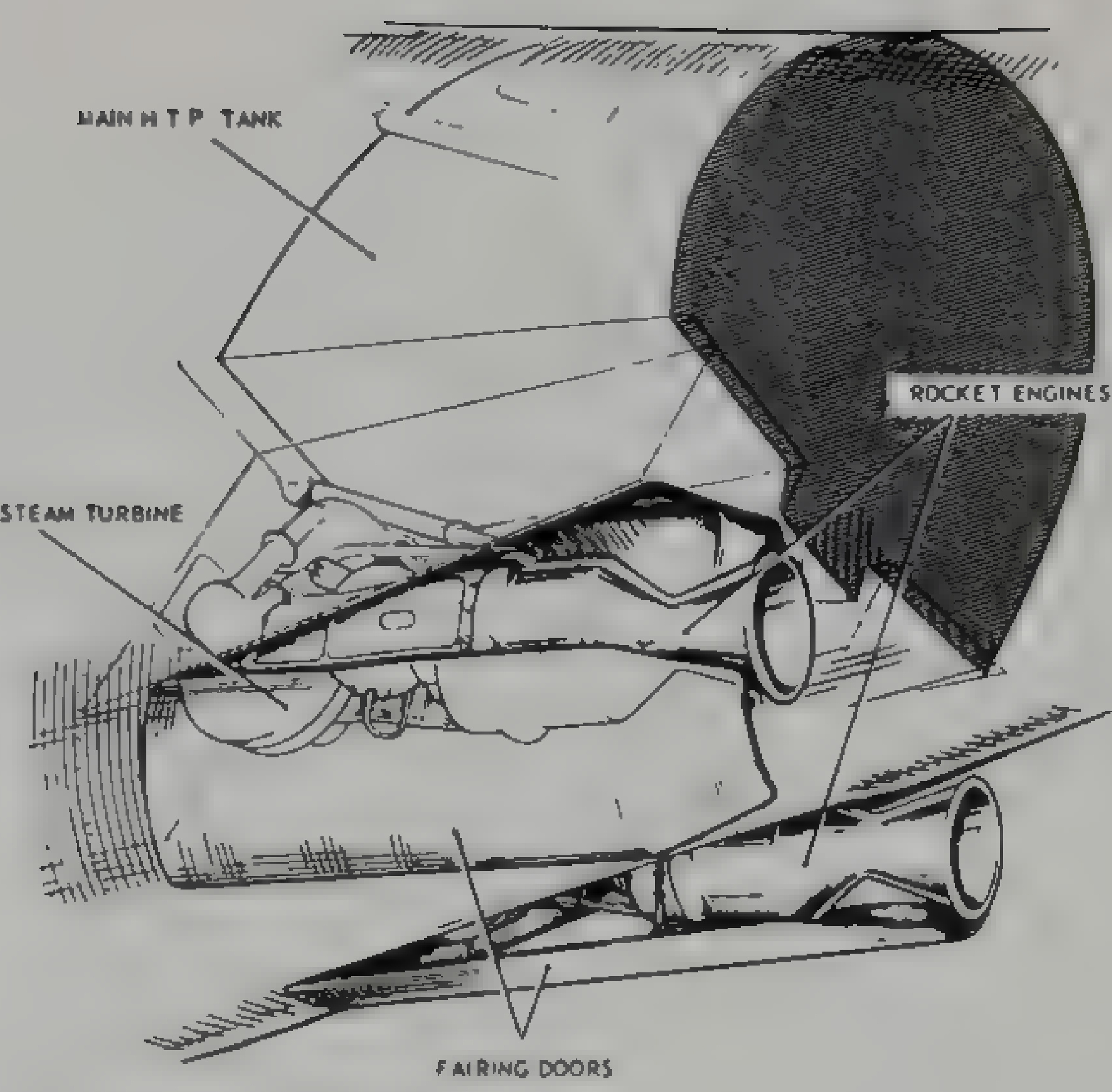
The South Africans proved to be very good people to deal with. In many respects they knew what they wanted, and in others were prepared to listen to



Buccaneer flight refuelling pod and pack.

advice, study the implications, then make a decision and stick to it. Some of the items which they specified would, in our opinion, be beneficial to the Royal Navy aircraft. There was time to incorporate them into the basic Mk 2 if an early decision was taken. Collins HF radio and the use of the Flight Refuelling Mk 20 series pod for the tanker role came into this category. At the time the bomb bay pack had been specified for the Royal Navy aircraft, but no action had been instituted. The strengthened undercarriage and higher-capacity brakes fitted also found an application to the later Royal Air Force version.

In the long-distant days when we lived in rooms with one small child, I took to



ROCKET INSTALLATION

A rocket installation is available to enable the maximum weights to be taken off from short, hot or high airfields.

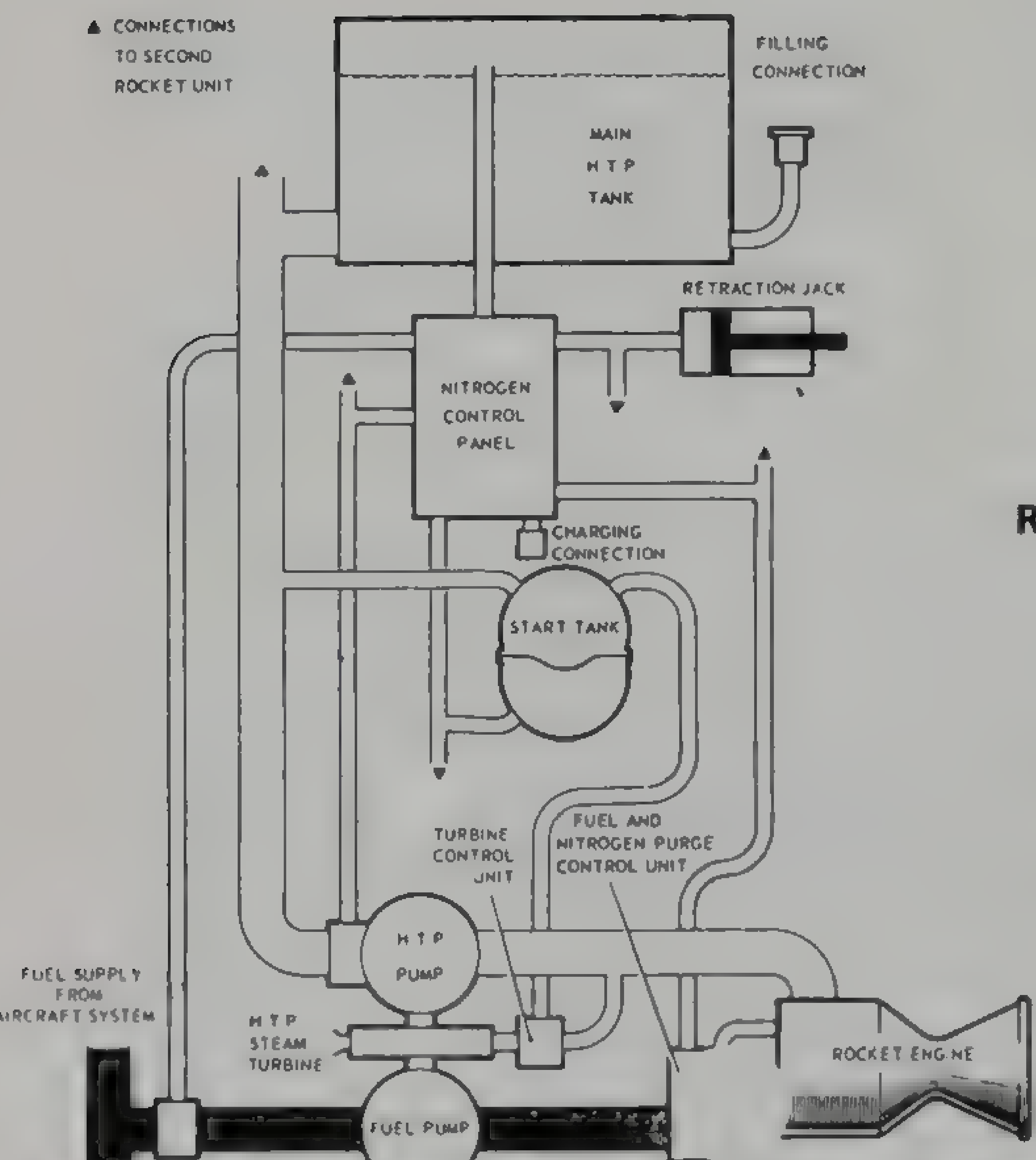
The installation is a two nozzle Bristol Siddeley B.S. 605 liquid propellant engine on retractable mountings in the rear fuselage.

The total thrust is approximately 8,000 lb. Sufficient oxidant (hydrogen peroxide) is carried for 30 seconds operation. The fuel (kerosene) is drawn from the aircraft fuel system.

The 30-second running time is sufficient to perform take-off and acceleration to safety speed at the highest possible loaded weight.

The liquid propellant engine is compact and reliable – it can be checked before take-off. It can be started and stopped at will.

The starting and stopping control is a single switch in the pilot's cockpit.



ROCKET SYSTEM DIAGRAM

Buccaneer rear fuselage rocket installation.

doing the evening washing up while Joyce put our son to bed, thus enabling us to get out earlier for a walk. The practice continued ever after. It required no mental effort and one was ensured of solitude, such that cogitation on the day's problems could continue undisturbed. Thus it was that, feeling unhappy over the engine-nacelle installation of the rocket motors, I conceived a retractable installation with the two motors positioned on either side of the arrester hook, with the HTP tank in the bay above. With this installation adjacent to the fuel jettison line, kerosene was readily available to complete the package, and this was the arrangement finally adopted.

Of course, in some quarters there was a great deal of apprehension about the use of HTP. We found one of the Viton compounds to be suitable for the HTP tank, cleaning and drying-out procedures for the system were established and, provided that extreme cleanliness was observed relating to oil and grease coming into contact with the HTP, and that plenty of water was available for hosing-down in the event of a mishap, the whole operation was quite painless. We developed an HTP refuelling/defuelling trailer, with all the supporting facilities, and used it successfully during our clearance trials.

The first Mk 50 Buccaneer flew in January 1965, contemporary with the seventh Mk 2, and was soon accepted by the South African Air Force. The remaining 15 followed at regular intervals up to April 1966. All of the trials, including the rocket-assisted takeoffs, went smoothly. This included clearance with the Nord AS 30 missiles.

A Buccaneer Mark 50 makes a rocket assisted take off, April 1965. *(BAL 20771)*

A Buccaneer Mark 50 at low level with enlarged wing drop tanks. *(BAL 20827)*

The powered wing fold was deleted, but withdrawal of the latch pins and folding of the wings could be done manually. This was a tedious process, against which only minor gains were made, and in later years we succeeded in preventing the Royal Air Force from making the same mistake. The advantages of folding wings for parking or stowing in the hangar are considerable.

No 24 Sqn of the South African Air Force reformed at Lossiemouth in May 1965, to train on the Buccaneer under the auspices of the Royal Navy. Initially Mk 1 aircraft were used, until the Mk 50s became available later in the year. The first eight aircraft flew on a multi-leg sortie to South Africa on 27 October 1965, during the course of which one suffered loss of control and crashed into the sea, the crew ejecting successfully and being rescued. The remaining eight aircraft were shipped out as deck cargo in two batches in August and October 1966.

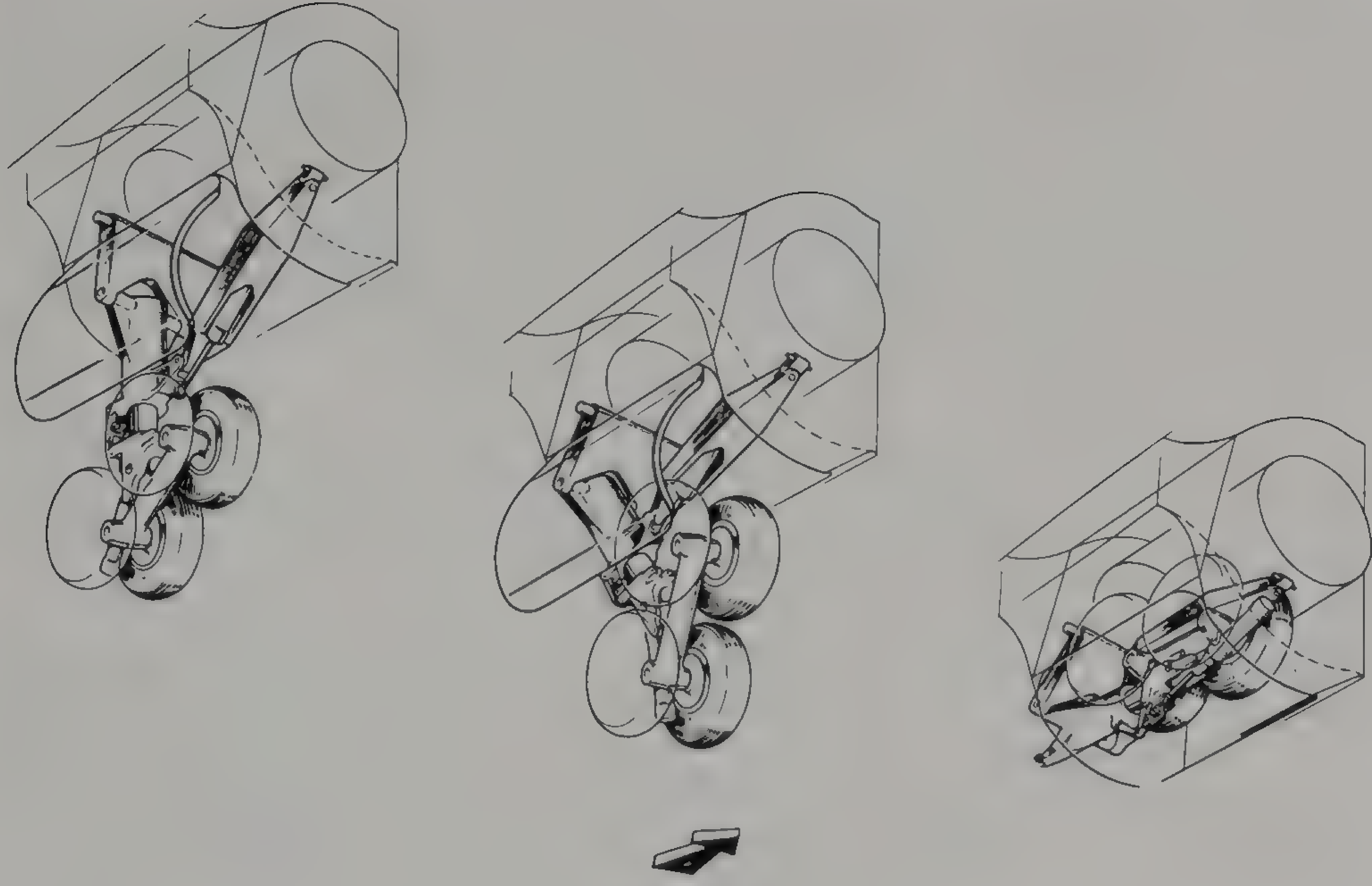
The political situation which had developed made it marginal whether the 16 aircraft ordered would be allowed to be delivered. It certainly precluded the placement of the follow-up order for a similar quantity, which had been confidently expected. From the technical point of view, the whole Mk 50 programme had been both successful and interesting, and certainly the aircraft had given good service over a long period. At the last count, attrition had reduced the 16 to six, but these were still operating.

Disappointingly, this was the only export success for the Buccaneer. Those who wanted it were not allowed to have it, and those who would have been allowed didn't want it — to some extent influenced by the failure of the Royal Air Force to adopt it at the time. The political constraints imposed are much greater for an aircraft which is essentially a bomber, and hence an aggressor, than they are for a fighter, which is essentially for the noble art of defence, but which is, of course, capable of offensive operations.

Low LCN Bogie Undercarriage

In 1963 we were still hoping to sell the Buccaneer for land-based operation, and were well aware of the limitations imposed by the high tyre pressure on the basic aircraft of 230 lb/sq in, giving an LCN (load classification number) of 35. The retracted position of the existing undercarriage lay between the wing spars to a stowed position under the jetpipe heat shield, and added very little to the frontal area of the aircraft. To give greater flexibility for land-based operation we studied a four-wheeled bogie undercarriage, with tyre pressure of only 100 lb/sq in, giving an LCN of 15-20.

The unit consisted of a telescopic leg with an oleo pneumatic shock absorber, the upper end of the leg being pivoted on a skew axis such that, with the appropriate linkage, the retracted wheels would lie partially astride the jetpipe. The bogie unit was located in the correct attitude for landing and rotated on retraction by a hop damper/jack mounted between the bogie and the lower end of the telescopic member. Structural changes to the inner wing to accommodate this unit were easily manageable, the increase in frontal area was quite small, and the weight penalty was estimated to be 200 lb. This excellent undercarriage was to feature in several proposals for land-based Buccaneers over the following years, but it was never adopted.



Buccaneer Bogie undercarriage retraction sequence.

Buccaneer 2* — Improved Weapon System for the Royal Navy

In 1962-63 a study contract placed upon Blackburn for an improved weapon system for the Buccaneer aimed at: increasing the accuracy of delivery of conventional weapons, increased safety during the attack, increased all-weather capability, and better availability and quicker operational turn round. This resulted in a report in March 1963 which proposed: an inertial navigation system, using a Litton platform; a central digital computer by Litton; a high-definition dual-band radar with search, ground mapping and attack modes; a separate terrain-following radar; an optically-matched topographical map and radar display, and a television sight display at the observer's station.

With the above would also come a general updating of equipment and associated airframe changes. The resulting aircraft was known unofficially as the Buccaneer Mk 3, with which it was intended to equip the squadrons operating from the new generation aircraft carriers, then at the firm planning stage.

However, due to cost, to the desire to make more use of equipment of British origin, but above all to political factors involving the future of the Fleet Air Arm, the proposals, whilst finding technical approval, stagnated and finally died. Nevertheless, forward thinking continued, and in July 1964 we were again tasked with the study of an improved weapon-system Buccaneer, but with stringent limitations on equipments to be considered. To avoid confusion with the earlier proposals, and to indicate that the changes proposed were less extensive and less expensive, the proposal was christened Buccaneer 2*, the results of the study being reported in March 1965. One proposal was the zero/zero rocket-assisted seat.

The carriage and use of television and anti-radar versions of the Martel missile were introduced into the requirements for the Buccaneer 2*. The restrictions placed on choice of equipment did allow a Ferranti inertial platform to be included, but with analog rather than digital computing. Within the terms of reference given, an adaptation of the Ferranti forward-looking radar, designed for the terrain-following mode in the TSR.2 and flown during its development in the second development batch Buccaneer, XK 487, was the preferred choice, although the long-range pick-up at sea of discrete targets, a prime feature of the Buccaneer's Blue Parrot, could well do with more attention.

The combination of this radar and the inertial system, even with analog computing, gave some enhancement to the attack system, although to aid increased accuracy a new but existing air-data system was proposed. The Service view was that primary flight information should be included in the pilot's HUD (head-up display) for which proposals were made.

For the observer's displays, two side-by-side near-HUDs were recommended. One would give a TV display either from the Martel missile or from the TV optical sight retained from the earlier studies. The other would display a topographical map driven by the inertial platform or the radar display, with the possibility that a combined matched display from both sources might be developed. The problem of rapid alignment of the inertial platform whilst at sea was addressed, and a transfer system from an already aligned platform proposed.

Changes to the airframe to incorporate the new system were extensive at the forward end of the aircraft. Additional length in the rear cockpit to accommodate the displays was obtained by recessing the seat into the bulkhead. Radar and the optical TV sight required a new nose, while the inertial platform, navigation and weapon-aiming computers and waveform generator were all to be mounted below the cockpit. This relative co-location eased alignment problems, and also minimized any electronic pollution into cables.

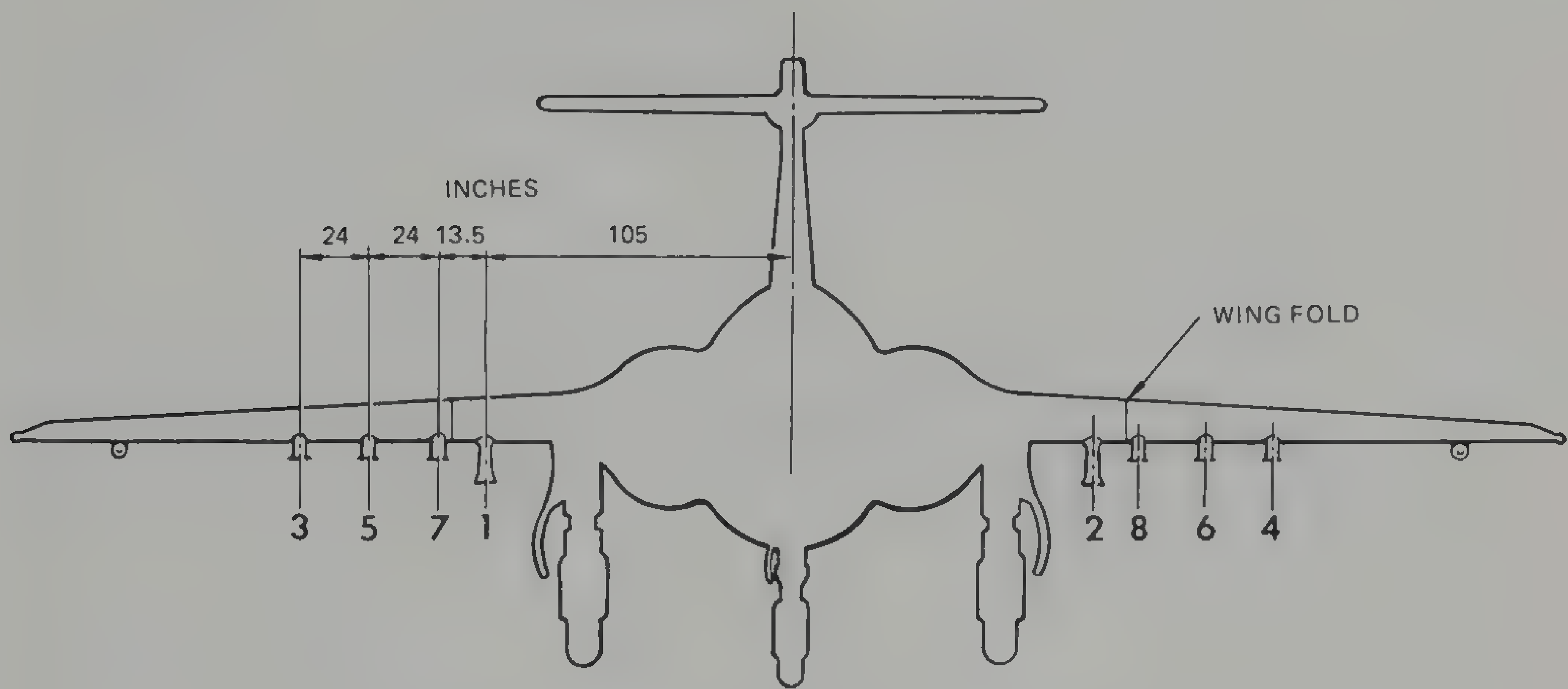
The basic Buccaneer has two independent cooling systems, one for the cabin and electronic equipment installed in the front fuselage, and one for the radio bay in the rear fuselage. The repositioning of equipment on the 2* rendered the existing capacity of the forward cooling system inadequate. It was proposed to operate two cold-air units in parallel, mounting both in the rear of the aircraft with a separate but smaller cold-air unit mounted forward to supply the aircrew ventilated suits.

The existing wing pylon arrangement on the Buccaneer was unsuitable for the carriage of Martel missiles. Apart from having a single-point ejection unit, their spanwise positions were incompatible. The existing stations were at 105 in and 139.5 in from the centreline.

For the 2* the inboard pylon for Martel carriage was placed outboard of the wing fold at station 118.5 in. The outer station was placed at 166.5 in, 8 in further outboard than necessary, to make room for a third pylon at station 142.5, permitting the carriage of three conventional bombs on each outer wing. The original inboard station at 105 in remained available for the carriage of wing tanks and flight refuelling pod when required. Use of this latter station would place limitations on the use of the outer-wing stations. The above is of interest for comparing with the later solution for the carriage of Martel missiles on the RAF Buccaneer Mk 2. No mention is made in the 2* proposals of any problem

with the wing-fold with the additional load on the outer wing, but this was addressed on the later Mk 2 conversion.

Hence, over a two-year period, two major but different proposals had been put forward to enhance the operational capability of the Buccaneer, although the second was constrained into keeping analog computing. The submission was ill-timed, as it virtually coincided with the announcement of the political abandonment of the new aircraft-carrier programme, and the running down of



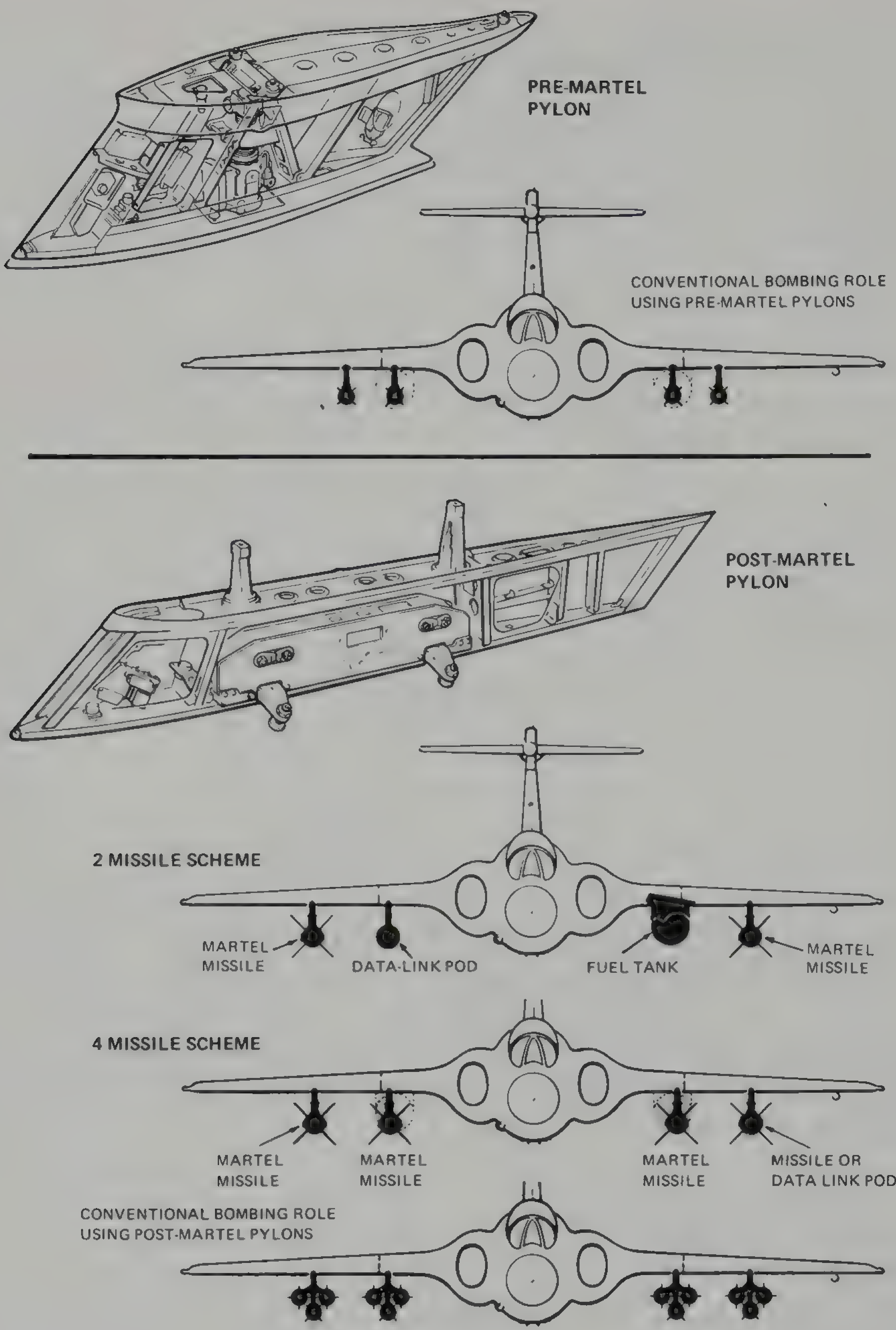
The Buccaneer Mark 2 wing pylon positions.*

the Fleet Air Arm. Nevertheless, the work done and the knowledge gained in these two investigations was never forgotten, and was put to good use in making further proposals for systems updates in the Buccaneer. For the record, the 2* report indicated that, for a go-ahead in mid-1965, an in-service date of mid-1969 was considered to be possible. The 2* was estimated to have a basic weight 800 lb greater than the Mk 2.

Buccaneer Mark 2 with Martel (later designated Marks 2B and 2D)

The demise of the Improved Weapon System Buccaneer, and at the same time that of the P.139 Airborne Early Warning aircraft, left the Brough design organization in a state of shock, with prospects of being grossly underloaded within the foreseeable future. Work from other Hawker Siddeley Aviation sites which were overloaded could, and in fact did, ease the situation to some extent, but the drive had to be on to obtain more indigenous work.

Although the long-term future of the Fleet Air Arm had been promulgated in an unfavourable way, operation of the Buccaneer from aircraft carriers was to continue, albeit on a diminishing scale, for a further 14 years. In our view, there also had to be a continuing requirement for land-based maritime strike operations. The nature of the combination of both targets and their defences gave an increased emphasis for stand-off attacks, and the Martel missile in both its anti-



Buccaneer wing pylon configurations — pre- and post-marked.

radar and TV-guided forms, which had been studied in the Mk 2* work, seemed to be well suited for this role. The adaptation of the current Mk 2 Buccaneer to operate with these missiles was therefore examined in some detail.

The pylons for wing-carried stores on the Buccaneer used single-point suspension of stores with a vertically mounted ejector ram. They were therefore fairly deep. Attachment to the wing was by three bolted fittings, two side-by-side at the front and one at the rear. The most modern stores were designed for two-point suspension, and for this the ejector ram lay horizontally in the pylon,

operating the vertical rams via a linkage. The pylon was hence much shallower, and attachment to the wing could be by two bolted spigots on the centreline of the pylon.

The main reason why the missile could not (on the 2*) be carried on the inner-wing station 105 was the foul which would arise between the missile wings and the undercarriage door. The solution chosen for the Mk 2 was a new station on the inner wing in line with the outer of the two original pylon fittings at station 108.5. This was sufficiently far outboard to avoid the door foul, but required two new fittings in the wing for pylon attachments. By making one coincident with the original forward position, the old pylon could be installed as an alternative to the new one by inserting an adapter into the new forward fitting. Structural changes to the inner wing to accommodate this were substantial but straightforward.

For a four-missile capability a pylon station at 162.5 was chosen. If a two-missile scheme was selected, with none carried on the inner wing, this could be moved inboard to station 150. In any case, the TV version required the carriage of a data-link pod which would be on the inner wing, and this in itself would require some structural modifications in that area.

With missiles on the outer wing, the power available in the wing-fold mechanism was at best marginal, and serviceability, mainly of details on the inner wing, had been poor. Changes required on the inner wing for the four-missile scheme justified the introduction of a new wing-fold mechanism which would have much more power and give greater reliability. For the two-missile scheme, the power requirement would be less, and with less work to be done in converting the inner wing the cost of the new wing fold could probably not be justified, although a 10 per cent increase in the jack power was a justifiable proposition.

With economy very much in mind, the Naval Staff seemed to be inclined towards the two-missile scheme until we pointed out that the conversion work involved was five-sixths of that for the four-missile scheme. As other contemporary work was proposed whilst the conversion was in progress, no time would in fact be saved, and they would finish up with an article which was almost as expensive but decidedly inferior. Very much in our minds at the time was the fact that, with the four new pylons and using triple ejector racks, we could double the maximum bomb load which the Buccaneer could carry.

After a series of meetings, most were convinced of the merits of the four-missile scheme, but a final meeting was arranged at the Admiralty to make the decision. As professionals we arrived in good time, checked the projection arrangements and waited for our important audience to arrive. Just before the appointed hour a workman in overalls appeared through a large hole in the wall and announced that he was installing air-conditioning ducting, and that in a short time he would be making a noise which would render any meeting in the room impossible. We could not deflect him, and neither could our important audience when it arrived. After a somewhat chaotic delay, an alternative room was found and the audience reassembled. Meanwhile, one of the Admiralty residents had folded up the portable viewgraph, transported it to the new room and set it up ready for operation. When we switched it on, there was a flash and loud bang, followed by a pall of smoke. By now it was lunchtime, and no alternative projector could be located, leaving the whole Martel conversion programme on the edge of disaster. As an act of desperation, I obtained a large

A Buccaneer Mark 50 with four AS 30 missiles, February 1966. *(BAL 21438)*

A briefing for the Buccaneer's entry into service at RAF Honington: Left to right, the author; Group Captain W. J. Herrington, Station Commander; and Wing Commander G. C. Davies, C O of 12 Squadron. *(BAL)*

sheet of white paper, stuck it on the wall behind me, assembled those who in a large room full of people were a combination of the most important and the most unconvinced, and sat them centre front. Then, holding the viewgraph transparencies up to the sheet of white paper, we proceeded with the presentation. It worked, and we got the decision needed, but it was a nerve-shattering experience.

One further structural matter is worthy of mention. The Martel rounds were very costly, and would not, if it was at all avoidable, be jettisoned prior to a deck landing, as was fairly common with iron bombs. To cater for the higher landing weight, some strengthening of the main undercarriage and associated fittings in the inner wing was effected, including a new fork and wheel. For the nosewheel, a Liquid Spring of increased travel avoided any increase in reaction, but a new fork was fitted. Thus, with the four-missile scheme agreed and the structural changes defined, it was possible to draw up a programme for the introduction of the new facility in build and also for retrospective conversion of existing aircraft, where both inner and outer wings were returned to jig, internal changes incorporated, and new skins fitted.

Rewiring and fitment of system black boxes was quite routine, but the problem remained of the observer's guidance display for use with the TV round, bearing in mind the limited fore and aft dimensions of the rear cockpit. Ferranti came up with an ideal solution of a display unit containing a vertical cathode-ray tube and an optical system such that, with appropriate modification to the observer's windshield, it could be fitted behind the pilot's seat but clear of the observer's ejection path. However, we were informed that Martel TV displays had already been funded for application to the F-111K and the UK Phantoms; they were not going to fund another, so we could make our choice of either of these. The Phantom unit was a cumbersome L-shape, quite impossible to put into the Buccaneer. The F-111K display was of a size and shape that would fit on the bottom of the Buccaneer cockpit with the observer's feet and legs astride it. Far from an ideal arrangement, but just feasible, so this was the choice reluctantly made. It is ironic that, in the event, the F-111K never happened and Martel was never fitted in the Phantom, whilst the Buccaneer has seen well over 20 years of service with Martel as a primary role.

Within weeks of the meeting in August 1966 the full programme was launched, with XK 527 being converted into the hack aircraft to undertake handling, flutter and initial firing trials. It flew on schedule in early 1968, and completed the programme successfuly. Two modified production aircraft, XN 974 and XV 350, were used to clear existing armament on the new wing pylons and then to complete clearance with Martel by late 1970. Deck trials followed later on HMS *Ark Royal* in 1972 and 1974 to bring the Martel conversion programme to a successful close.

P.145 Proposal for a land-based Buccaneer

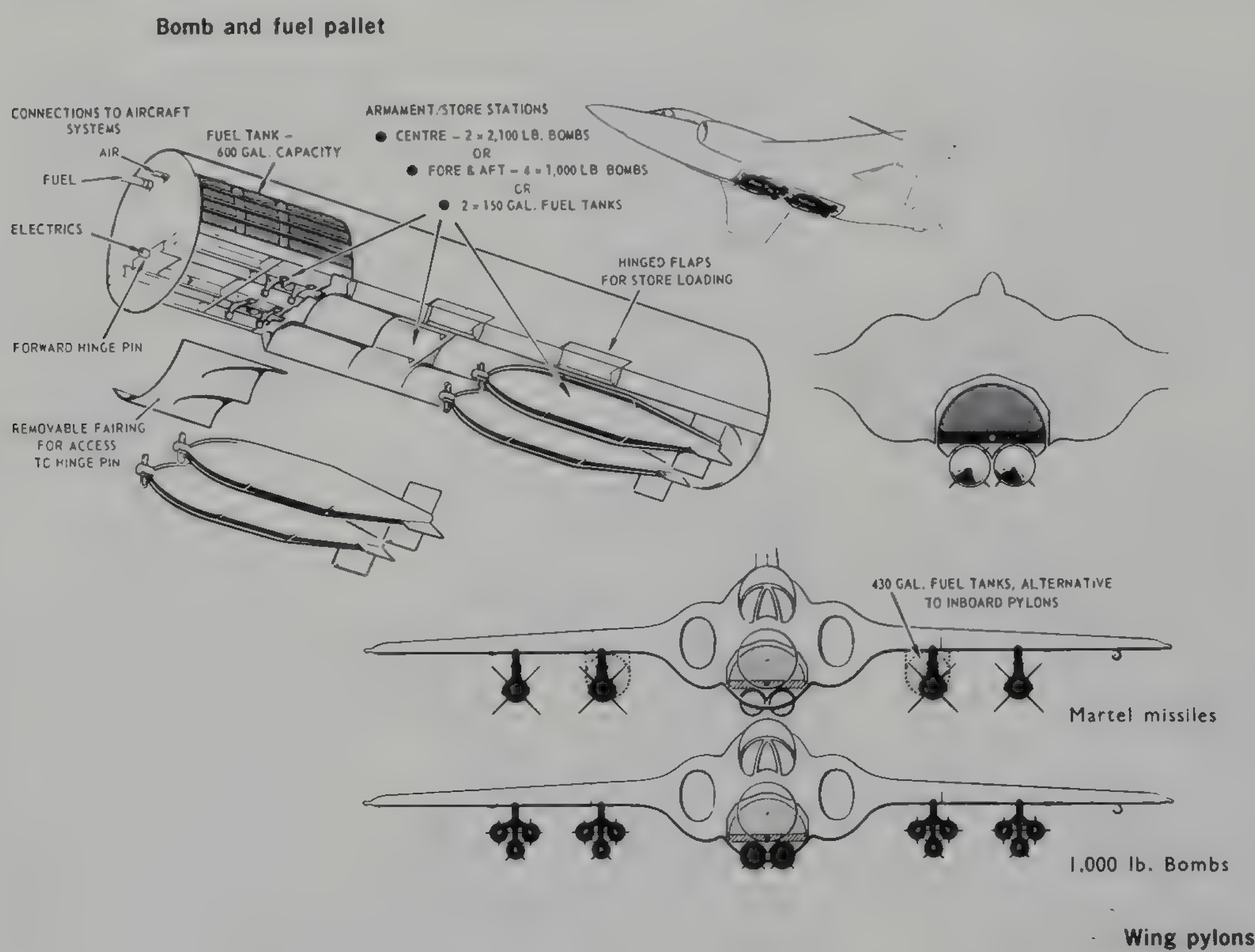
Still in the hope of selling a land-based version of the Buccaneer, either to the Royal Air Force or for export, the P.145 proposal was produced in October 1966. This took advantage of the work already done on the Martel wing stores carriage, the rocket assisted takeoff of the Mk 50 together with its 430-gallon

wing tanks, the bogie undercarriage design, and the Improved Weapon System studies, in addition to which some new ideas were introduced.

To minimize changes of design in the front fuselage it was proposed that the inertial platform should be mounted in the radio bay where, with the removal of the master reference gyro, there was room. Loss of accuracy compared with the forward installation of the 2* proposal would be small compared with the gain obtained relative to the existing system, particularly as the very rigid fuselage would not deflect significantly. Harmonization with the nose-mounted equipment could be effected via a mirror system, which could be fixed to the underside of the fuselage for this purpose.

To minimize development costs it was proposed that the nav/attack system should include navigation and weapons-release computers developed in conjunction with the Ferranti inertial platform for the UK Phantom F-4M. The choice of pilot's HUD was left open. The existing Buccaneer unit was one option, but several more modern and comprehensive displays had become available. A similar situation related to the radar. There was a choice or retaining Blue Parrot, fitting the previously discussed Ferranti forward-looking radar, or — ideally, if funds were available — to develop the dual-frequency X/Q-band radar which had been included in the Mk 3 proposal of 1963. Definition of the weapons system was very much a matter of customer choice, and we had no customer.

Another new feature offered with the P.145 was for a large reconnaissance pack, picking up with the airframe attachments for the bomb door. This con-



The P.145 fuel and stores carriage.

tained a range of cameras, infra-red linescan and a sideways-looking radar, the system being similar to that fitted in the Phantom reconnaissance pod on which we had worked in collaboration with EMI. This pack completely filled the weapons bay, but the four wing stations remained available for the carriage of any additional stores.

Realising the importance of range, and knowing that since the original design of the Buccaneer most stores had been adapted to withstand the environmental conditions of external carriage at the relevant speeds, a fuel and stores pallet was proposed which, in the same way as the reconnaissance pack, picked up the airframe attachment points which had been provided for the bomb door. The stores were carried semi-recessed on the underside of the pallet, with fairings as required between them and the pallet. The upper part of the pallet was a 600-gallon fuel tank. To obtain access to equipment in the bay, the pallet could be rotated 90° either way.

Within a maximum takeoff weight of 62,000 lb on a typical operational profile, the P.145 could carry 4,000 lb of bombs for a radius in excess of 1,400 miles, 10,000 lb of bombs for over 800 miles, or the maximum bomb load of 16,000 lb over a radius of 400 miles, all with a takeoff run of under 4,000 ft. Unfortunately, at this stage the Royal Air Force was politically committed to the purchase of the F-111K. Due to their lack of involvement with the project, no other party came forward with interest, so the formidable and versatile P.145 remained a paper project.

Buccaneer Mark 2 for the Royal Air Force

Suddenly in early 1968 the F-111K was cancelled, and there emerged from the Ministry of Defence a statement that the Buccaneer was after all to see service with the Royal Air Force. Aircraft to be given up by the Royal Navy were to be transferred, but in addition a further 26 were to be built. (Ten of these had been partly built, but cancelled after HMS *Victorious* was written off by a fire which broke out as a major refit was being completed). Later an additional 17 were to be ordered, which, with a small number to be built for use at Government establishments, was to keep the Buccaneer in production until late 1977, by which time 209 had been built.

There was no time to express our feelings at this unexpected arising, as discussions with the Air Staff started immediately on the standard to which the Buccaneer would be supplied to them. Certain things were easy to decide. With no carrier limitations on maximum weight, use of the Mk 50 430-gallon tanks and wheels and brakes was suggested, and a landing light was a necessity. Triple ejection racks fitted to the Martel pylons was favoured. Changes of minor impact to some of the radio equipment were readily agreed, as was the fitment of ILS and specified ECM equipment. The range of armament stores to be carried was extended. A comprehensive reconnaissance facility was required, for which a pack similar to that offered in conjunction with the P.145 was our response.

Once again we proposed an updated nav/attack system, again based on the P.145 proposals, although the MRG 2 (master reference gyro Mk 2), already accepted for fitment to the Royal Navy aircraft, was a cheaper but less-effective alternative to the inertial platform. Fitment of the Ferranti FLR (forward-

looking radar) was recommended but, in the end, the Royal Air Force settled for retaining Blue Parrot but with the earlier proposed development of monopulse resolution enhancement added.

By the autumn of 1968 enough had been agreed and an Air Staff Requirement issued for both design and flight-test programmes to be drawn up and initiated. The new reconnaissance pack fell under the economy axe at an early stage, before any hardware had been produced. Even the triple ejection rack proposal suffered the same fate, but after considerable work had been done which included flight tests with the full 16,000 lb bomb load.

With the degree of agreement reached, modification of the first ex-Royal Navy aircraft began, and the first few were delivered to RAF Honington in October 1969 to allow the formation of 12 Squadron. By March 1970 the first of the new-build aircraft were to be delivered to enable the first of the two RAF Germany squadrons, No 15, to form in October 1970 at RAF Honington, prior to taking up station at RAF Laarbruch shortly afterwards.

Of course, design, manufacture and clearance of the Royal Air Force items was a progressive affair over several years, but 1970 saw the Buccaneer in service with the Royal Air Force in earnest. The degree of enthusiasm shown by the crews was particularly gratifying to us.

Spring 1970 was quite special for me as I was invited to fly with 12 Sqn on a typical operational sortie, and this took place from RAF Honington on 19 March. Due to a combination of circumstances, I had not up to this time flown in the Buccaneer. The station decided to rectify this matter and, in order to help establish good relations with the local populace had, unknown to me, invited television to attend the occasion and to conduct interviews afterwards. It was as well that I landed fully serviceable.

Immediately prior to start-up it was realised that the ferry fuel tank which could be fitted in the bomb bay was not only in but was full of fuel. The switch to transfer this fuel is in the rear cockpit. Used to demonstration flights with VIPs in the rear seat, the ground crew broke into a panic until someone suggested that Mr Boot might be able to operate the switch. I placed my left hand on the switch and raised my right thumb, and with the panic over off we went.

The flight in XV 347 during which we were accompanied by XV 351 took us northwards at 30,000 ft to Sunderland, followed by a plunge descent with full airbrake to 250 ft above the sea, and then at speeds of between 450 and 550 knots through the North Yorkshire Moors, over the company airfields at Holme on Spalding Moor and Brough, down the Humber and then over land back to Honington. I remarked on how smooth the flight had been, and the reason for the wry smiles in response became obvious during the flight back to Brough in the Dove when, with a 40-knot surface wind, we were tossed all over the place. The only adverse after-effect I suffered was a sore beer pot for several days, due to prolonged pressure on it from the g-suit during some of the manoeuvres, which had been rather prolonged.

There is certainly no substitute for the designer flying in his aircraft for him to appreciate its good and bad points. Whereas the general flying characteristics exceeded my expectations, the nightmare for the observer of navigating fast and low overland with the system as fitted was patently obvious. Even though I had

RAF Buccaneers of 237 O.C.U. *(8701404/B.Ae.K.)*

Ready for take off: the author and his pilot, Wing Commander Davies, before the author's flight with 12 Squadron. *(792G)*

been flying over territory which I knew very well, it was difficult for me to keep up with it.

Whilst the Royal Air Force in its initial conclusions had settled for the current system with the MRG.2, we continued to press for reconsideration of our updated system with the inertial platform. In particular, we gave presentations to RAF Germany and to senior members of the Air Staff in early 1970. The two factors which seemed to worry the Royal Air Force most were the lack of adequate ground mapping and terrain-following equipment, for which no complete solution was obvious. The lack of these militated against any significant expenditure on the other system update proposals. It was apparent to us that a further factor was involved. If the Buccaneer in the overland strike role was made too good, and this would require significant expenditure, there could arise pressure in some quarters against the committed programme on the MRCA (later Tornado), whose officially predicted (as opposed to the actual) in-service date was a mere two to three years later than the likely availability of the fully improved Buccaneer. This attitude would be difficult to criticise.

P.149 Proposal for the Royal Air Force

The discussions with the Royal Air Force which took place in 1970 on possible improved weapons systems did not lead to any surprises. Indeed we had anticipated many of the points raised, and, following the discussions which defined the initial standard of Buccaneers for the Royal Air Force, in March 1969 we produced the P.149 proposal. This was aimed at giving increased operational capability and flexibility by the incorporation of a number of modules, most of which were capable of incorporation independently of the others.

Top of the list was a new navigation system based on a rear-fuselage Ferranti inertial platform as on the P.145, but using digital computing for both navigation and weapon aiming. The combination of radar and other sighting sensors for search, terrain-following, ranging and ground-mapping resulted in a range of choices being offered.

One option took advantage of work then under way at Ferranti to offer a ground-mapping capability via a 30 in by 6 in spinner aerial operating in Q-band. The spinner, rotating about a vertical axis, would be chin mounted under the main radome. However, this would necessitate a smaller scanner for the X-band radar than that fitted with the Blue Parrot, and the previously considered Ferranti FLR would fit in well. This latter would give a terrain-following capability in addition to search and radar ranging, but these would be selectable, rather than simultaneous, functions, and the maximum search range would be degraded by 40 per cent compared with that obtainable with Blue Parrot.

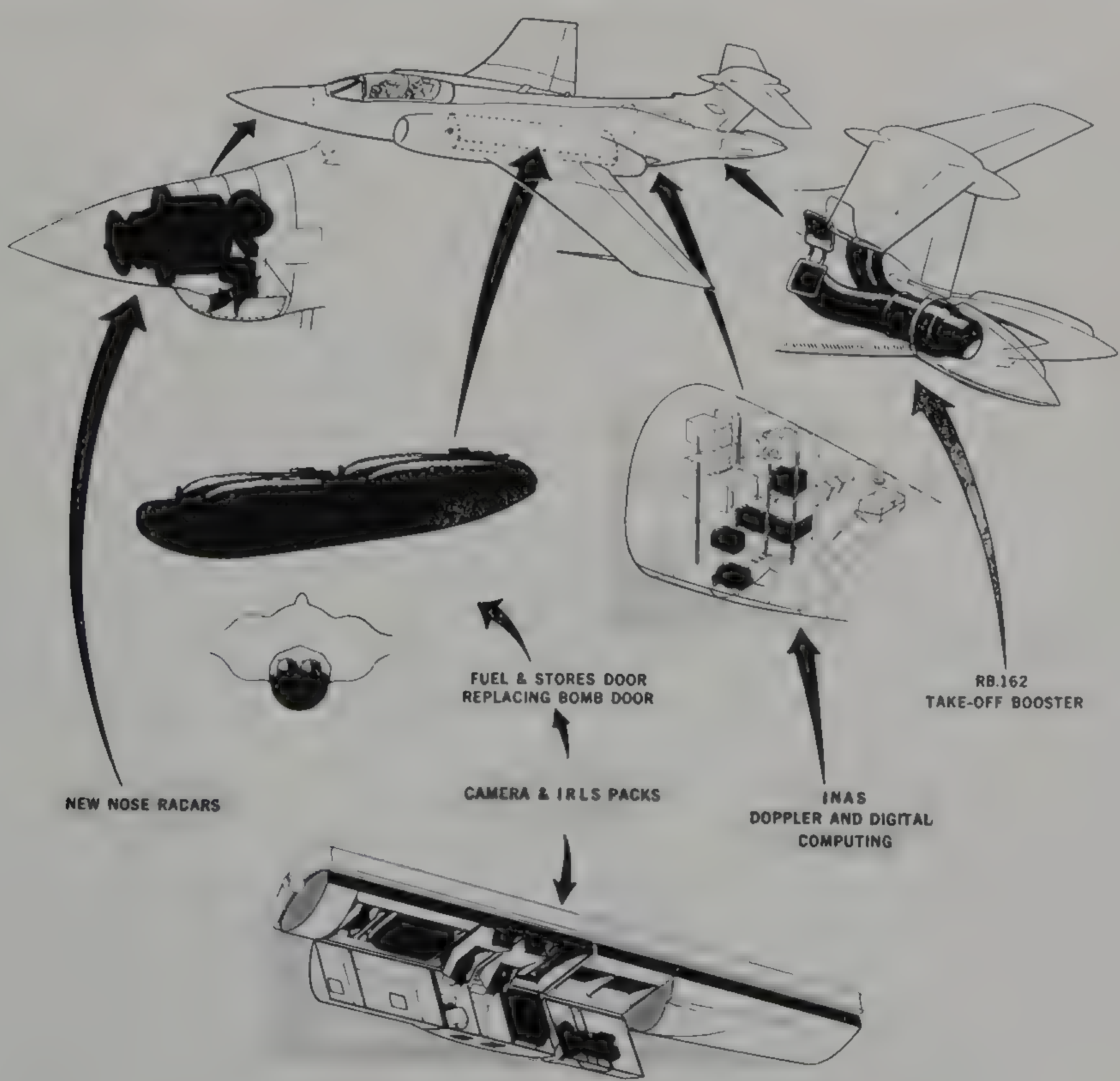
Another alternative would be to retain Blue Parrot and mount a small terrain-following radar in a chin pod containing possibly a radar to be purchased from abroad specifically for this application, or alternatively as a cheaper solution the equipment which had been used in the Vulcans and was now becoming redundant, although this was by no means ideal.

Terrain-following, if fitted, could be done entirely by the pilot in a manual mode, in which case a more modern pilot's HUD would be essential. For the alternative of an automatic system, the provision of the necessary degree of inbuilt integrity into the flight-control system was thought to be of near insuper-

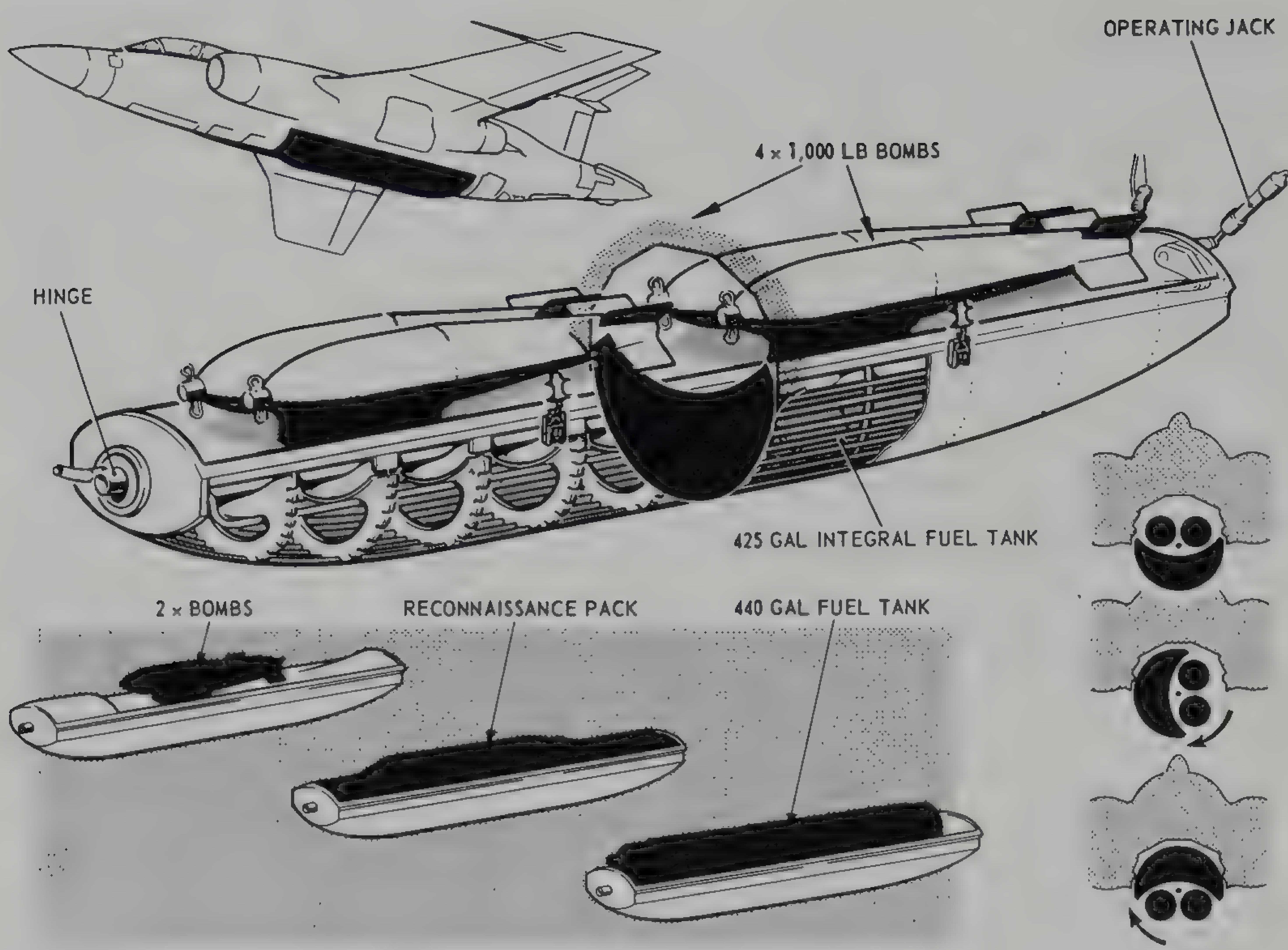
able difficulty. An ingenious solution, proposed by Boulton Paul, appeared to give a cheap and adequate solution, avoiding the need to develop a triplex system. This proposal merely added a second operating system which, however, was not connected to the control surfaces. The two systems were to be monitored and, in the event of any disparity between them, the automatic terrain-following mode would be cut out, with a 'safe' signal being applied to the control system at the time of cut-out. A reconnaissnce pack, very similar to that proposed with the P.145 project was another module included in the offer.

As an alternative to the assisted-takeoff rocket-motor system, the installation of an RB.162 turbojet, which had been developed as a vertical lift engine, was also offered. This, like the rocket motor, was to be mounted in the rear fuselage, but the airbrakes had to be opened some 20° with the engine running. This sounded strange, but would in fact have negligible effect on the takeoff run, which with the booster engine would be 25 per cent less than that of the standard Buccaneer. None of these proposals finally found favour, although the inertial navigation system came very close to being adopted. The remaining new feature in the P.149 proposal was the bomb-door tank, which in fact was already being discussed for application to all Royal Air Force Buccaneers.

An in-service date of 1973-74 was offered, based on an early go-ahead. With the usual delays in project authorization, and the by no means unknown hiccups in equipment supply, it could have been two to three years later, which would certainly have brought it too close to the predicted MRCA dates.



P.149 design features.



P.149 Bomb Door Tank.

Bomb door tank

A subsequent review of the fuel and stores pallet left a feeling of uneasiness about flow conditions at the extreme rear of the pallet. Thinking further about this — again while doing the washing-up at night — an alternative approach to the increased-range facility came to mind.

The dimensions of the cross-section of the internal weapons bay were not necessarily determined by the stores carried, but by the arc swept by the corners of the door whilst it was rotating. If this arc was swept over the outside of the door, with front and rear of the resultant shape faired off, the door itself, even allowing for stores carrier mountings, could be an integral tank. A check on the possible capacity showed that this arrangement could hold 70 per cent of the fuel carried by the pallet, and with a less draggy installation it appeared to be a very good proposition. After studying several possibilities, an annular fuel coupling around the door hinges was designed, and a completely viable arrangement was on offer.

The concept of the bomb-door tank was left on the shelf for some time, but came to the rescue when another difficulty presented itself. As stated the RAF Buccaneer was to make use of the 430-gallon under-wing tanks as supplied to South Africa. At a meeting at the Ministry of Defence finalizing the specification for the RAF Buccaneers I was asked whether any difficulties were likely to arise. As everything under discussion had been used successfully in other applications, I confidently answered in the negative. I was wrong. The increase in wing tank capacity was obtained largely by a longer nose. We failed to appreciate that, without the rocket motor at the rear of the aircraft, the aircraft centre of gravity

would be further forward. When we came to test the RAF aircraft with the large tanks we found that the takeoff was impeded by the pilot's inability to raise the nose at the desired speed. This was not helped by the fact, which we discovered much later, that the particular Buccaneer being used for these tests had, for some totally inexplicable reason, a ten-knots higher nosewheel-raise speed than any other Buccaneer we had ever tested. Nevertheless, arithmetic showed that there was a problem. It was then that we recalled the bomb-door tank, and realised that with this and the existing wing tanks the Buccaneer would have more range than with the larger tanks alone. Additionally, the bomb-door tank could be filled, leaving all four wing stations free for the carriage of offensive stores and still give a worthwhile extension to the range of the basic aircraft.

Adoption of the bomb-door tank and retention of the existing wing tanks was therefore the answer to the centre of gravity problem, and also provided some useful bonuses. A dummy tank was flown, and the drag increase with the door closed found to be less than 2 per cent of that of the basic aircraft.

The proposal to take this course met with the usual barrier of bureaucracy. There was no operational requirement stated, it was not in the specification, and it would cost money (although some of it would be saved by not having to manufacture the 430-gallon tanks). Fortunately, one or two key members of the Air Staff saw the operational flexibility which would result and, with a sympathetic Project Director at the Procurement Executive (at least he was sympathetic once he saw the Air Staff giving him some ammunition), several meetings were held. As a result the proposal was formally submitted and approved for the bomb-door tank to become standard on all Royal Air Force Buccaneers. When introduced into service it was greeted with great enthusiasm by the aircrews; it was almost something for nothing. It also eventually found its way out to South Africa.

One of the factors in arguing the case was to get the bomb-door tank into the new-build aircraft as early as possible. This saved wasted money on conventional bomb doors, and it was gratifying that, to assist in this, Hawker Siddeley Aviation put in its own money to keep the programme under way whilst the formal discussions were proceeding.

P.157 Buccaneer

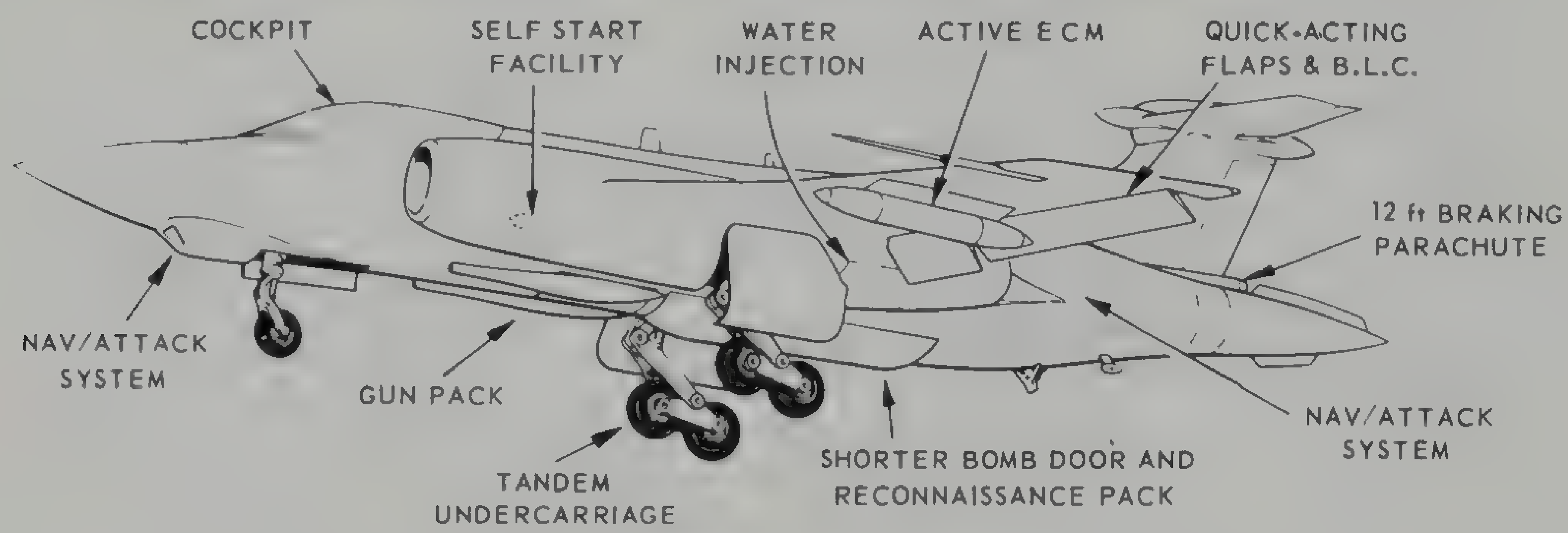
In spite of the repeated rejection of most of our proposals, ideas continued to flow. As one never knows what situation lies around the corner, in May 1974 we put together what was to be the last proposal for a major variant of the Buccaneer, the P.157. This was intended to adapt the Buccaneer for the CAS (close air support) role, whilst retaining the strike/interdiction capability for overland operation. The maritime strike role was not considered to be applicable to this version.

For the nav/attack system, the digital inertial system was again proposed, with a new modern pilot's HUD. With the appropriate rear cockpit displays, a 7 in extension of the cockpit was recommended by introducing a slice between the front and centre fuselages where a manufacturing joint existed. Low light TV and a laser ranger/marked target seeker were installed in a blister under the nose, which itself contained an entirely new radar installation. A dedicated terrain-following radar of an existing type was mounted under a similarly known

ground-mapping radar. Both manual terrain following, using the new HUD, and automatic terrain following using the system described for the P.149 were included.

The forward third of the weapons bay was taken up by a twin-gun installation, and a new shortened door, including an integral fuel tank, fitted behind it. New features on the airframe included an APU (auxiliary power unit) which would also provide a self-starting facility.

Airfield performance improvements included a 12 ft braking parachute for landing and the introduction of 'quick-acting blow' for takeoff. This consisted of very rapid lowering of flaps and aileron droop and the selection of blow at the appropriate stage of the ground run (a concept similar to the technique used on the Harrier of vectoring the jet nozzles late in the takeoff run). This gave a 35 per cent reduction in ground run, compared with the Buccaneer Mk 2.



The P.157.

To assist soft-field operation, but to avoid the structural changes necessary to incorporate the previously described four-wheel bogie undercarriage, a tandem-wheel arrangement was proposed which required no change to the airframe attachments and also used the existing main-leg forgings. Tyre pressure was 160 lb/sq in, and the corresponding LCN was 20. The development programme included in the P.157 proposal offered an in-service date of 1981-82.

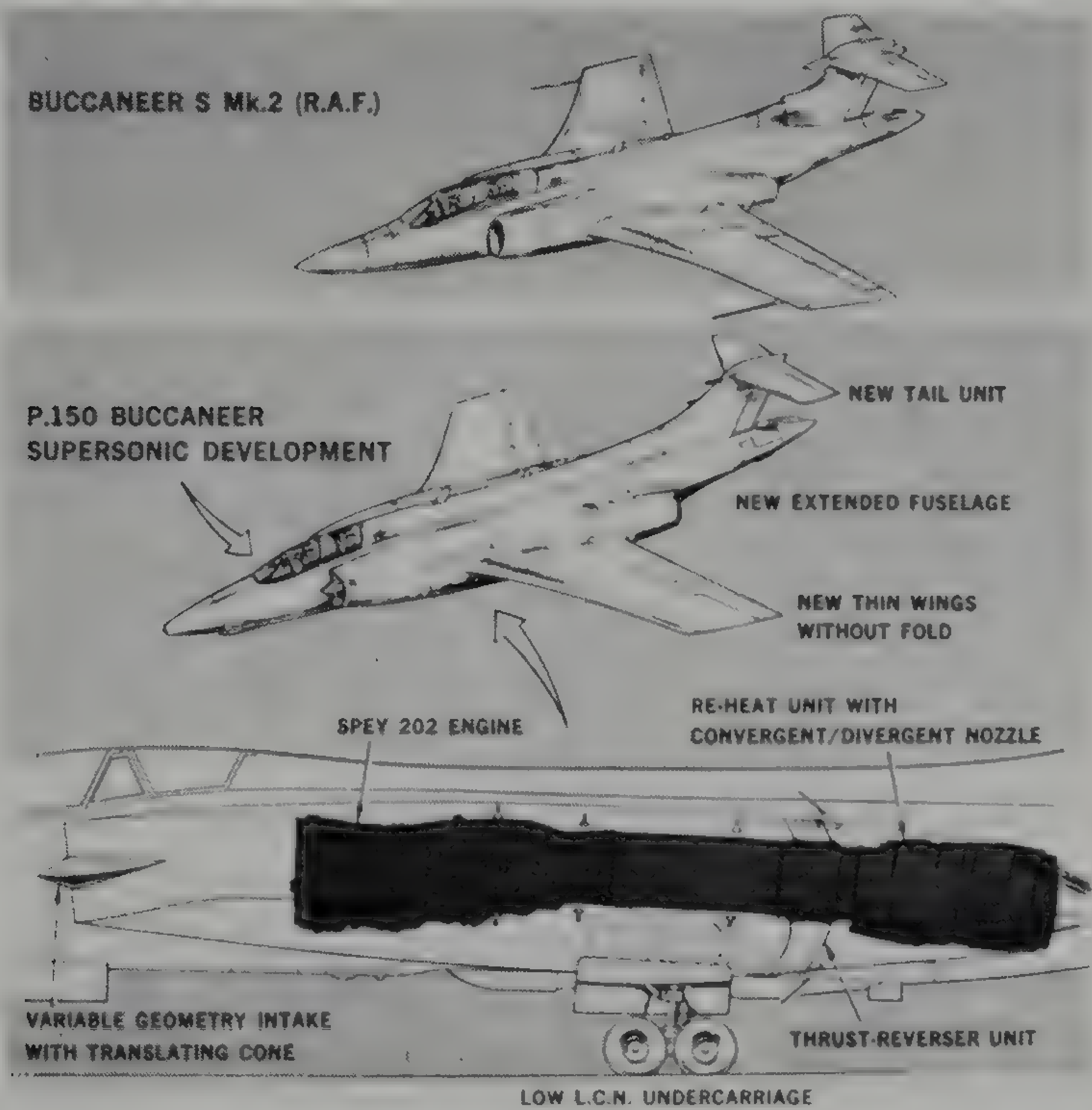
Whether this was a cost/effective proposal to augment our close air support capability is open to doubt, but at least it could have been in service by the early 1980s. The contemporary official requirements of AST 396 and the later AST 403 both foundered, leaving a gap which will last until well into the 1990s and possibly beyond year 2000.

P.150 — the last supersonic Buccaneer proposal

The P.140, previously described, was a supersonic Buccaneer intended as a multirole fighter, basically to undertake the duties subsequently carried out by the UK Phantom. The P.150 was our response, in 1968, to a surprising request from the Air Staff to put forward proposals for a supersonic version of the Buccaneer using reheated Spey engines. This was concurrent with their studying options on the Buccaneer Mk 2, and one must assume that the intended role was strike interdiction, which had previously been scheduled for the F-111K. Not for us to reason why, but meet the requests of the customer to the best of our ability.

For the P.150 the rear fuselage was extended by 3 ft, eliminating the area-rule bulge; the centre fuselage was extended forwards by 2 ft, and a 1 ft extension

was added to the rear cockpit. The non-folding 6 per cent thick wing was attached to the centre fuselage in the manner used on the Buccaneer. Due to the change of aerodynamic loading a new design of tail unit was required. As a substantial weight increase was inevitable, the four-wheel bogie undercarriage was incorporated. The engines were Spey 25R, as fitted to the Phantoms, but with a transition pipe through the spar rings followed by a thrust reverser in front of the reheat pipe.



P.150 design features.

A maximum speed in excess of Mach 1.8 was predicted. Basic weight was 7,000 lb greater than the Buccaneer Mk 2, in addition to which 8,000 lb more fuel was carried including a fuel-and-stores pallet. At this stage the alternative of a bomb-door tank was not an option. Radius of action was very similar to that of the Buccaneers then in service. The predicted date for entry into service was 1975, five years later than the formation of the first squadron of Buccaneer Mk 2s. At the time we considered this to be a paper exercise, and this indeed proved to be the case.

Avionics update for the Royal Air Force

Previous proposals for updating the Buccaneer avionics had been either in response to the long-term plans of the Naval Staff or, in the main, unsolicited proposals to give a really effective overland strike/interdiction capability. By the mid-1970s it was obvious that the Tornado would be undertaking these duties almost as soon as a new variant of the Buccaneer could be produced. It was also known that, at some time in the future, some of the Tornados were to be deployed on maritime strike duties.

We could not help noticing that a sufficient number of Buccaneers had fatigue

lives to take them into the mid- to late-1990s, that their range was in almost all missions greater than that of the Tornado, and that their high-subsonic speed should suffice for the maritime strike role, particularly with Martel and Sea Eagle stand-off missiles. On the basis of 'horses for courses' it seemed best to deploy the maximum possible numbers of Tornados in the overland role, and to retain a fleet of Buccaneers in the maritime strike role — for which they were originally designed — for as long as possible.

The Blue Parrot radar was supreme in the long-range maritime search and attack mode, provided that, in spite of its antiquated technology, it could be kept working. Thus, there was no point in looking for an alternative. Fitment of the inertial platform in the radio bay, with its inbuilt digital computing, would not only assist the observer's workload but it was highly desirable for interfacing with new-generation weapons.

Digitizing weapon-release computation, and providing a modern pilot's HUD with its associated additional facilities, seemed to be worthwhile additions. My last working day at Brough in 1977 was spent in London presenting the operational concept and the technical proposals to the Air Staff. They seemed to be impressed, but worried on how to get the matter actioned.

It only took another five years, when, with financial stringencies still to the fore, a reduced update programme was at last implemented. Flight trials with the modified system have taken place, and at the time of writing delivery of updated aircraft to the RAF has commenced.

The Buccaneer and fatigue

It was said in connection with the avionics update proposals that an adequate number of Buccaneers would have fatigue lives to carry them into the mid- to late-1990s. This was based on the evidence available at the time, from both calculation and test data.

At the time of the design of the Buccaneer basic structure, around 1956, theoretical data on fatigue and fracture mechanics was, to say the least, sparse. The aircraft specification called for a given fatigue life with flight conditions appropriate to the Hi-Lo-Hi sortie of that specification. During the design phase, stiffness rather than strength was found to be defining the scantlings — material thicknesses — and the application to the resulting structure of good engineering practice in relation to fatigue life was, on the evidence available, considered to produce the desired result.

An early Mk 1 development batch aircraft was allocated for fatigue testing, and this was eventually commissioned, taking advantage of loadings which had been measured in flight during the programme. These fatigue tests continued over a number of years. They demonstrated, subject to minor repairs which had to be made from time to time, that the life of the airframe, in terms of damage rate and hours flown, was two to three times greater than the specification requirement. A good thing it was too! Experience has shown that the average damage rate per flying hour is double that deduced from the specification mission. In training units, where sorties are shorter with often more low-level flying, it is about treble. On some individual aircraft, operated without fleet management for fatigue life, the factor could be more than four. Nevertheless, based on the full-scale fatigue test results, the life of the Buccaneer fleet appeared to be satisfactory.

It will not have escaped notice that the test airframe was an early Mk 1, whereas most of the operating was to be done with the Mk 2. At the time of the design of the Mk 2 an assessment of the structural changes was made, and the conclusion was reached that the results of the tests under way would still be applicable.

In time, three things were to contradict this. First, the extended wingtip introduced during Mk 2 development had a greater effect on loading than had been anticipated. Second, there is always liable to be a corner in a complicated fitting where a stress concentration sneaks in without being calculated, and which in the normal course of events never gets measured on test. Thirdly, changes in air-bleed ducting and powerplant fire zoning introduced on the Mk 2 were to have a most unexpected effect.

The first two matters mentioned were eventually discovered after the loss of two aircraft in Royal Air Force service, each of which caused major concern accompanied by flying limitations until the problem was resolved. In one case, inspection and more frequent replacement of a pin overcame the crisis.

The second failure had more serious implications, as a main spar fitting had failed. One partial remedy was to remove the extended wingtips, and restore the original square-cut ones, thereby reducing the loads. Detailed periodic inspection of the region of the component which had failed, and provisioning of a stock of new components for use as and when shown necessary from the inspection routines, all found a place in returning to normal. During the investigation of the failure the affected component had been inspected in situ in all aircraft, supplemented by a strip examination on a number of selected aircraft. To make absolutely sure for the long-term future, a relatively new aircraft, XN 982, was removed from the fleet and positioned at Brough to become the subject of a new full-scale fatigue test. The problem with this is to run the test at a high enough rate to catch up with the fleet leaders in quick time.

The third of the three problems in fact chronologically happened first. A Royal Navy Buccaneer S.2 at Singapore in late 1971 was discovered by visual inspection to have a severely long crack running in the web of a main-spar ring, close to the flange. This of course created a panic. Penetrant dye, fluorescent penetrant dye, eddy-current and magnetic flaw-detection inspection techniques were used progressively, as each succeeded the other to check the entire fleet. The results were not encouraging. Fatigue damage of widely varying extent was detected on many of the aircraft, some damage showing up with the most sophisticated inspection techniques at a distressingly low value of fatigue damage factor.

The cause was eventually identified. There was a 4 in diameter hole in the web at the bottom of the spar ring, through which passed a main air bleed pipe. In the change from Mk 1 to Mk 2 the main spar ring became a boundary of a fire zone, so a seal had to be introduced around the duct. This fire sealing gaiter was fixed to the spar rings by six bolts, for which 0.19 in diameter holes were drilled, equally spaced and symmetrical about the vertical. The fatigue crack had originated from one 0.19 in hole, initially inwards into the 4 in hole but then running outwards towards the flange before turning to run virtually circumferentially.

It emerged that, during the design of the Mk 2, in the lack of test evidence and with the not unreasonable assumption that the maximum stress occurred at the vertical position, it had been calculated that, even allowing for stress-raising

factors because of the hole, the stress in the plane of the 0.19 in hole at the position of the crack origin was less than the estimated stress at the vertical position. On this basis the installation had been cleared. Subsequently, test evidence became available, and this showed that the plane of maximum stress in the ring was not at the vertical at all, but was in the plane which ran right through the offending hole — which by sheer bad luck had been drilled in exactly the wrong place. One may well observe that it is not good engineering practice to drill holes in primary structure to attach items of no structural significance. Needless to say, a different method of locating the fire seal gaiter was immediately devised.

With the by now much greater knowledge of the theory of fracture mechanics, and with a rapidly increasing amount of test data, decisions had to be made on flight limitations to be imposed, dependent upon the amount of damage detected, possible short-term measures which might be taken to alleviate the situation, and hopefully to find a long-term action to eliminate the problem. Flight limitations were agreed which would keep much of the fleet flying.

Interim fixes dressed out detected fatigue damage within the 0.19 in hole and, provided that the damage was confined to within the hole, it was ballized: a hard oversize ball was forced through the hole, exerting a compressive stress on the area and hence delaying the onset of further damage.

Two alternative long-term solutions were designed. The first consisted of putting reinforcing plates over the affected area of the spar ring. This required very careful and skilled reaming, with access for this none too easy, so a degree of uncertainty had to exist over its application over the fleet. The alternative was to manufacture and fit a new spar ring, this time without the 0.19 in holes and, to make sure, with additional material around the 4 in hole. The uncertainty with this answer was any problem which might arise due to movement as the old rings were removed.

The foregoing is easy to relate in retrospect, but the period of several months over which the crisis existed put a lot of people under very heavy pressure. One had to be grateful for a dedicated and competent staff, who devoted themselves to resolving the problem. With the technical problems resolved, a meeting was held at the Ministry of Defence to decide which rectification action was to be taken on the aircraft in service. For a time, no conclusion was reached. Then one of the Service officers present asked, 'What does the Chief Designer think?' Taken by surprise, I took a deep breath and replied, 'I would sleep easier in my bed at night if the new rings were fitted'. 'That's good enough for me', he said, the rest of the meeting agreed, and the course was set.

When it came to doing the first fit at Brough, we were particularly worried about the centre fuselage sagging with the old rings taken out. We carefully arranged supports, and took out only one ring. We then had the new one jig-bored from it overnight, to fit it the next day before taking out the second ring. All went well, and none of the anticipated problems arose. So quickly was confidence gained that, only a few weeks later, I walked through the shop during the two-weeks works holiday shutdown and observed two Buccaneers lying there for the duration with both rings removed. Later, the work was also done at an RAF Maintenance Unit, and the whole fleet brought up to standard.

On fatigue, as has been proved on a number of occasions, one can never be sure, but with the back-up of the new fatigue tests on a full Mk 2 airframe, hope-

fully no more shocks will reveal themselves. There is every confidence that, with the occasional husbandry which always seems to be required, the Buccaneers will run their full allotted span without any further fatigue problems.

Epilogue for the Buccaneer

For nearly 25 years, from the time that I did the initial B.103 design in the Project Office until I moved to Warton at the beginning of 1978, with the last 12 years as Chief Designer, the Buccaneer formed a major part of my life. Ten years later it is still in service, and is likely to be for most of another decade. It seems premature to write an epilogue, but two quotations already made could well form part of the final one. From a Senior Officer at Central Trials and Tactical Organization, circa 1982:

> 'The Buccaneer may be an old aircraft in design terms, but it still outperforms many of its more sophisticated juniors in both speed and range. Perhaps future designers should turn more towards this excellent aircraft for their model. Certainly penetration speeds in the transonic range seem to be the norm for the future'.

From a Commanding Officer of a Buccaneer Squadron in RAF Germany, in 1984, when the squadron was being disbanded and the Buccaneers in Germany replaced by Tornados.

> 'So far as I can tell, everyone who's flown the Buccaneer has always ended up with a great love for the aircraft, and it has its own personality which endears itself to everyone. It is well liked because of its inherent stability at low level, where it is a sheer delight to fly. It has earned and kept the respect of NATO allies, particularly on Flag Exercises, Red Flag in the United States and Maple Flag in Canada, where at 100 ft it has scored over many other types'.

That is exactly what we set out to achieve all those years back. These comments, coming from members of the service which for 14 years rejected the Buccaneer, give particular pleasure.

A Buccaneer S Mark 2B with Pavespike laser guided bombs showing the lines of the bomb door tank. *(B.Ae.)*

Chapter 10
Sister Design Firm for the United Kingdom Phantoms

The purchase of American-built McDonnell F-4 Phantom aircraft arose from a disintegrating programme on the Hawker P.1154. Hawker Aircraft had produced the experimental P.1127 Kestrel to demonstrate the application of vectored thrust for vertical or short takeoff and landing with the revolutionary Pegasus engine. This had four rotating nozzles, with the forward pair ejecting fan air and the rear pair ejecting the normal hot jet efflux. The resulting aircraft was small, and of necessity subsonic, but it did become the subject of a tri-national experimental programme involving the United Kingdom, the United States of America and Germany — the only basis at the time that the programme could have proceeded financially. Although Germany did not continue beyond the demonstration stage, the UK and USA eventually collaborated to produce the Harrier AV-8A and Harrier II AV-8B.

However, with the P.1127 having adequately demonstrated the concept, Hawker addressed themselves to designing an aircraft with a supersonic capability. Apart from having thinner wings and more refined lines, something radical in the way of change was necessary on the powerplant. The solution adopted was to incorporate the equivalent of reheat in the front nozzles, burning fuel in the fan air, known as PCB (plenum-chamber burning). A new engine, on the same principles as the Pegasus but with PCB, the BS. 100, was proposed to give over 35,000 lb of thrust, a 75 per cent increase over the contemporary Pegasus. An aircraft in the over-30,000 lb weight bracket, with a Mach 2 capability, then became possible.

Thus, during 1961 and 1962 the Hawker P.1154 was designed to meet a requirement circulated by NATO, NMBR.3. The design eventually won an international competition, but political infighting and the lack of NATO central funding (project finance was, and still is, dependent upon contributions from the individual participants) resulted in the requirement lapsing. In spite of this setback, in early 1962 a purely national joint Royal Air Force and Royal Navy Staff Requirement, OR.356/AW.406 emerged as a Hunter and Sea Vixen replacement, based on the P.1154. In May 1963 Hawker were given an initial go-ahead.

As the project evolved, differences betweeen the individual requirements of the two Services became increasingly obvious such that, in addition to the originally intended common airframe, two significantly different variants of a

common basic design were mooted. Controversy raged for some time with no agreement being reached (a similar situation arose in the United States, where there was political pressure for a common version of the F-111 to satisfy both Air Force and Navy requirements). In both countries the eventual outcome was the same, with the Navy opting out of the project. This happened in the United Kingdom in February 1964, and the purchase of Phantoms — which of course needed the biggest carriers — for the Royal Navy as the Sea Vixen replacement was announced. Work on the Royal Air Force variant of the P.1154 was to continue. This decision, however was short-lived, as in the first half of 1965 the P.1154, along wth the AW.681 V/STOL transport aircraft and the TSR.2 were all to be cancelled. Purchase from America of the F-111 in place of the TSR.2, was one decision taken at this time, itself to be cancelled in 1968 in favour of the Buccaneer. The Royal Air Force fighter requirement was to be met by increasing the already decided purchase of the Phantom, with, in addition, a limited buy of an operational version of the subsonic V/STOL P.1127, to become famous as the Harrier.

With the initiation of the Phantom order in mid-1964 a project office was formed in the Ministry of Aviation, based at first on a purely naval project with Captain Ken Hickson RN as Project Director. He was a man of strong ideas, and he insisted on a more integrated and self-contained project office than had up to then been the norm, and he also saw the advantages of supporting the in-service fleet from a United Kingdom industrial base. There was also the wish to include the maximum UK content in the project. MACAIR (McDonnell Aircraft) had shown enthusiasm for a Rolls-Royce Spey engined Phantom, as part of their worldwide marketing strategy to give better range and performance than the standard J79-engined Phantom.

Hindsight can be an expensive commodity. For various mainly good reasons the reheated Spey, for which a development programme was instituted for this application, did not produce the anticipated performance advantages over the J79. Whilst MACAIR had based their policy on an expected order for 400 aircraft from the United Kingdom, with other worldwide sales of the variant to follow, in the end only 170 Spey-engined Phantoms were built, making it a very expensive programme.

The maximization of UK content in the programme resulted in the incorporation of many British components, and the manufacture of some airframe components in the UK. Worth special mention in this context was the build at Warton of the very tricky rear fuselage.

In addition to the long-standing association between Brough and the Royal Navy, there was a large degree of commonality between the Buccaneer and the Phantom which would benefit not only from the expertise developed but also from the rigs and other facilities which had been set up in support of the Buccaneer. It was on this basis that Captain Hickson invited Hawker Siddeley Aviation, Brough, to become sister design firm for the UK Phantoms, with terms of reference: 'To provide the same level of support in all aspects after delivery of Phantoms to the United Kingdom as would have been provided if the aircraft had been designed and built at Brough.'

In September 1966 an agreement between Hawker Siddeley Aviation and MACAIR was signed, under which MACAIR agreed in broad terms to supply Hawker Siddeley Aviation with the basic 'know-how' necessary for them to

carry out the tasks set to them by the Ministry. This agreement made the HSA task possible, but in the meantime important steps had to be taken. In the autumn of 1964 top officials of HSA and MACAIR met in St Louis and agreed that the necessary collaboration between the two companies should be effected. In January 1965 I was therefore directed to St Louis to agree a working arrangement.

With the incredible uncertainty at that time of the whole future of the UK aircraft industry, it seemed to be a happy situation to be getting alongside one of the major US companies in an industry which was — as ours should have been — booming and prosperous. The proposed task would also allow us to keep employed an efficient technical team which had been painfully built up over many years, and which we hoped would be kept available for future United Kingdom originating activities.

I was, however, uncertain of our reception by the St Louis team — 'Who are these foreign upstarts, who think that they are going to take over our airplane?' In the event, I need not have worried. With this and subsequent experience on other collaborative ventures I found that, provided that they are not subject to undue constraints or political limitations, competent professional engineers always respect one another and will invariably find a way of working together.

When dealing with failures or other problems, it is more than helpful if, in addition to knowing what was done in the first instance (and this can usually be obtained from drawings or manuals), one can also know why it was done in a particular manner. Such knowledge is normally available only to those who have been involved in the evolution process. My proposal in connection with this was to have senior engineers of the various disciplines integrated with the design team at St Louis during the design and development of the UK Phantoms, which were designated F-4K for the Royal Navy and the F-4M for the Royal Air Force. Whilst, in principle, the work in hand would only cover changes to obtain the new versions, it was hoped that a good working knowledge of the aircraft as a whole would emanate from the exercise.

Such a proposal could exile senior personnel for two years or more, so personal as well as professional factors had to be taken into account in setting up the operation. To ensure that nothing was omitted, I took with me the team leader designate, John Howland, and also his wife. In order to break any ice which might accrue, I took with me the slides of the lecture of the design and development of the Buccaneer, which I hoped would convince the MACAIR engineers of our capability.

We flew out on a Sunday, leaving just as the death of Sir Winston Churchill was announced. The arrival at New York was interesting, as there had just been a severe snowstorm and the runway and taxiway had to be cleared. Our resultant passage over the ground, passing between huge heaps of snow was distinctly bumpy. Due to our delayed arrival a frantic dash for our connection to St Louis was necessary, but with special arrangements made for our luggage we made the gate just in time, and took up our seats near the rear of the aircraft.

It turned out to be one of the earliest Boeing 727s, which had just entered service and about which my knowledge was very little. After takeoff I noticed what appeared to be the reassembly of a disintegrated wing taking place as the flaps were retracted, so I resolved to watch more closely as they were extended for the intermediate landing to be made at Cincinnati. From where we sat the

wing forward of about the maximum thickness was not visible, so when the triple flaps were fully extended the visual effect of this remarkable system was quite spectacular, but more was to follow. As we neared the ground, with what we subsequently learned was a very strong cross-wind blowing, the starboard wing dropped alarmingly. With some further peculiar motions, we thumped down safely on to the runway. Jean Howland who was sitting next to me wanted to leave the aircraft, saying she had no faith in the pilot. I told her to stay put, for had he not got us down safely? I believe that two aircraft were lost shortly afterwards under similar circumstances due to cross wind effects on the centre engine, so maybe we were very fortunate.

At St Louis we were met and taken to the Ramada Inn. Here, with snow and a temperature of 15°F, we found that our rooms were across an open space which included a frozen swimming pool, so we found ourselves running the gauntlet of the weather many times during our stay. We also learned on our arrival that the state of Missouri was dry on a Sunday, and we had not bothered to bring any duty-free with us. Gasping for a drink, after a long and at times trying journey, we awaited the arrival on a later flight of Cyril Elliott and his Rolls-Royce team who were by then regular travellers to St Louis and whom we were sure would not have made the same mistake. Unfortunately, their flight was seriously delayed by the weather and, with local midnight behind us, we retired to bed disconsolate and still thirsty.

Monday morning saw a MACAIR car collecting John and me and delivering us to our contact, M. G. (Mert) Walker, who was assistant to the Technical Director, Kendall Perkins. Before dealing with the formal technical discussions, for which a week was allocated, it is worth relating two enjoyable, but now unrepeatable, off duty evenings.

The first was dinner on the *River Queen*, a true old Mississippi steam paddle boat which was moored at the riverside at St Louis. It had been featured in several films, and had the various ports of call emblazoned along the sides of the superstructure. She operated partly as a restaurant and partly as a museum of the old river boats, and exuded an atmosphere such that down in the saloon one could almost smell the cigar smoke and hear the gamblers calling the cards. To me it was unforgettable. Sadly, a few years later, she sank at her moorings and was a write-off.

The second occasion was a visit to the Opera House in Gaslight Square. Gaslight Square was an area lit by typically old Parisian style gas lamps, and full of character. The Opera House was a total misnomer, for it consisted of two converted shops joined into one and operating as a bar and, more importantly, providing a home for the Singleton Palmer Jazz Band. If you like New Orleans jazz, which I do, it provided a great atmosphere in which to sit, drink and listen to the music which had one unique feature. Singleton Palmer himself played the tuba — not, as one might expect, as a normal bass backing but with a musical dexterity which would do credit to a trumpet player. I treasure the two records which I brought home with me. Gaslight Square was a casualty of the race riots of the 1970s. It became a no-go area, with the Opera House along with all of the other establishments ceasing to function.

Initial discussions with Mert Walker quickly found us with similar philosophies on both engineering and organization, giving a natural lead into what we should jointly do and how we should do it. By the end of Tuesday afternoon we had

virtually concluded the arrangements, so, wishing to let Brough know the progress which we had made before they went home that night, at 9.00 pm I left a dinner party to send off a cable from the only place open at that time of night, which was at the airport. With the cable safely despatched, I returned to the dinner party only to be asked by my host what the panic had been about, as was it not 3.00 am in the UK? With a six-hours time difference between the two establishments, in my enthusiasm I had got the sign wrong.

During the week we toured the MACAIR establishment, meeting many of the senior personnel. We formed a particularly strong bond with the then Phantom Project Engineer, Fred Steele — a real character and a fine engineer who, when he eventually retired, was presented by the Brits, both civilian and Service, with a bowler hat and rolled umbrella, and he sported these on all subsequent public appearances.

The arrangements made involved having, under John Howland but integrated with Fred Steele's team, a structural engineer, an aerodynamicist, a powerplant engineer, an equipment installation engineer, an avionics engineer, and an armament engineer. Most of them were there for two years, and a few considerably longer. Later, engineers from product support, technical publications and jig and tool departments were resident for periods of varying length. The whole operation went remarkably smoothly, and the HSA personnel on their return to Brough played an prominent role in the UK-based implementation of becoming the Sister Design Firm.

During the week of our January 1965 visit to St Louis several interesting comparisons between the Phantom and the Buccaneer came to light. Both are roughly the same size, and they flew for the first time within a month of one another, the Buccaneer in April 1958 and the Phantom during May. Up to the point of first flight both man-hours and the number of drawings were remarkably similar. On the other side of the coin, at the time of our visit the production rate of the Phantom was ten times the maximum rate achieved on the Buccaneer line, and later it increased to 20 times. In addition, over the years the number of major variants introduced was far greater for the Phantom. This scale of production signifies the major difference between the aircraft industries of the two countries although many of the difficulties experienced by the UK industry in the 1960s were politically self-inflicted.

Structural engineering of the two types had much in common, although the relaxed limitations for operation from US super-carriers allowed a folded width nearer to 28 ft than to 20 ft, and through this a thinner wing was practicable. Weight restrictions did not inhibit the use of reheat. Both of these factors were necessary for a supersonic fighter, for which role the Phantom was primarily designed. MACAIR were particularly proud of their rear-fuselage design, with Nimonic skin and 'shingles' to allow for expansion arising from the use of reheat.

The hydraulic systems for both flying controls and general services, and the electrical generation and distribution systems, were remarkably similar, there being only detail differences. This commonality of approach certainly helped to cement the brotherhood.

Both aircraft used boundary-layer control by blowing engine bleed air over the flaps and leading edge. On the later F-4J variant the Phantom also went for drooped ailerons, as was the case on the Buccaneer from the outset. MACAIR then also discovered that tailplane maximum lift was inadequate. They added a

fixed slat to the tailplane leading edge, and were very interested to find that we had applied leading-edge blow to the Buccaneer tailplane to achieve the same objective. At a later date MACAIR introduced a wing leading-edge slat to improve combat manoeuvrability, reminding us of our original proposal for the Buccanner outer wing.

In the late 1950s hydraulically operated, manually signalled, flying controls were the rule, plus an autostabilization facility. There were limits to what could be done. The wide flight envelope of the Phantom precluded the fine tuning for high-speed low-level flight that was accomplished on the Buccaneer. Those who have flown the Phantom fast and low seem to have been happy, but in this particular regime the Buccaneer is decidedly superior — and so it should be, for that is its primary role. Today, compromising for different missions presents little problem with modern digital computing, electrical signalling and active controls.

To return to the events of the week in St Louis, on the Monday I had offered the Buccaneer lecture to Mert Walker. This he accepted, so the next morning I placed the slides in his office. Up to 3 pm on the Thursday no more was said on the matter. I was across in the in the Chief Test Pilot's office when the telephone rang with the message, 'You're on at 3.30.' I dashed to Mert's office, grabbed the slides and we went up to the prescribed room, to find it full with Kendall Perkins himself in the chair.

I handed the slides to the projectionist, who then found that the plastic mounts were too thick to fit into his carousel. He said that no alternative was available, and that the show could not therefore go on. Shattered, and still suffering from the mad dash, I contemplated the situation. The slides were in a compartmented box in the correct order. I asked the projectionist if he could drop them in manually and, when moving on to the next slide, catch the one already in the projector when he moved it on. After some thought he said that he could, but that the slides might not be in the right order when I reclaimed them. Telling him that they would be in the right order when they went in, and that what state they were in afterwards was my problem rather than his, we went ahead, British improvisation once again triumphing over adversity.

Having got started, the talk seemed to go well, with Kendall Perkins interjecting with questions and comments throughout. As I finished the talk he started to wrap up the proceedings, when I expressed a willingness to have a free-for-all. Some hour and a half later we finally did adjourn, but I found the exchange of views on a wide range of topics both fascinating and enjoyable.

The following morning I asked for a list of those who had been present. When I got it I was glad that I had not had it before the talk, for I had been faced with much of the might of the entire MACAIR technical organization, and I could well have had a major attack of stage fright. There must be little doubt that sessions such as this contribute significantly to ease working together, and I was fortunate to have had such an opportunity.

On the way back to my hotel with Kendall Perkins he bemoaned the fact that they were now saturated with specialists, and that most of their people who had had an all-round capability had retired. Nevertheless, they don't seem to do too badly!

Friday saw the arrival of Cdr John Glendinning RN, from the Defence Staff of the British Embassy in Washington, for a wash-up meeting. I flew back to

Washington with him on my way home, leaving John and Jean Howland to pursue domestic arrangements. It was a memorable flight, for a blinding snowstorm was in progress at St Louis, but by some miracle most flights seemed to be arriving and departing on schedule.

Saturday saw me sitting in my hotel room in Washington, writing my report and watching on TV the funeral of Sir Winston Churchill. In those days with just Telstar, satellite coverage was available only over limited periods, so the programme was a mixture of real-time transmissions via the satellite and film flown over during the day. With live coverage of anything from anywhere these days, we don't always appreciate the progress which has been made. On Sunday, having completed my report, in a temperature of 15°F and on packed snow and ice, I went on a walkabout in Washington. I induced a cold-weather failure of an already damaged knee cartilage, which subsequently required an operation — my third of this type.

Monday saw me at the Embassy, where John Glendinning kindly offered to have my report typed for me. The evening flight to London followed, where on arrival I was expecting to fly to Leeds and then motor to Brough. To my surprise, a company car was awaiting me, and I was whisked up to Brough in time for a quick lunch, ruined by jet lag and a stomach which said 'breakfast'. Then straight into a Board Meeting which, after discussion, endorsed the arrangements proposed, and a telephone call put through to the Ministry to inform them. We were rather surprised at the extent of their knowledge, subsequently explained when I learned that the 'with it' staff at the Embassy had taken an extra copy off my report, while typing it for me, and had then bundled it into the diplomatic bag which crossed the Atlantic in the same aircraft as I did!

The design phase at MACAIR completed, the initial flight trials of the Spey-Phantom took place at St Louis, after which the prototype aircraft were flown to the Brough flight test base at Holme on Spalding Moor. Eventually a total of 13 aircraft were involved in the UK-based clearance trials, with one at Rolls-Royce Hucknall on propulsion work, with much of the other flying being done at A&AEE at Boscombe Down. This work was largely completed in 1970-71.

Instrumentation and support of the development fleet was effected by HSA Brough and, when the in-service fleet was established and modification programmes started rolling through, one of the T2 hangars at Holme on Spalding Moor was commissioned for this purpose. In addition, a complete avionics and weapons-system rig was commissioned, as had been done for the Buccaneer systems.

In the early stages of the Phantom programme, the ratio of technical work to shop-floor work arising was eight times that on the Buccaneer, and doubts were expressed on the economics of our role. With time, the shop-floor content built up to a more acceptable value. In the long term, as production of the Buccaneer ceased, the work content on both aircraft levelled off at roughly equal levels.

Throughout its life the Buccaneers had been towed by road in both directions between Brough and Holme on Spalding Moor. Its 40 per cent greater width made the Phantom a problem, although a special trailer was designed and built to overcome some of the difficulties. However, as each Buccaneer originated at Brough a facility for road transport between there and Holme on Spalding Moor was mandatory. The Phantoms, on the other hand, were programmed to fly into Holme on Spalding Moor for their rework programmes, so it was logical to do

Phantom F4K XT 596 with high lift devices extended, January 1988. *(BAL 3238/1)*

Phantom F4M XV 406 with a reconnaissance pod on the centre line. *(BAL 24033)*

the work at the airfield site for which one of the unused hangars was adapted. However, in 1983 Holme on Spalding Moor was closed down, and the flight-test centre moved to RAF Scampton. the Phantom modification activity was then transferred to a hangar at Brough, and it is now a common sight to see both Phantoms and Buccaneers trundling along the A15 and across the Humber Bridge — as I write, the world's largest bridge span — on transfer between the two establishments.

In the course of dealing with support of the Phantom, much of the traffic was of a routine nature, but two major problems came to the fore. One was as a result of American practice for a far lower standard of interchangeability than we had expected, based on UK standards. The other, in spite of all the test work done in the USA, was an outbreak of fatigue problems at a rate which initially caused great concern. At one stage we expected a crisis every six weeks. Eventually, most problems were solved, but so serious did it look at one stage that one aircraft, XT858, was taken out of service and subjected to fatigue testing at Brough — tests which at the time of writing are still continuing. Royal Air Force aircraft are, in the main, used for longer lives than their American counterparts, leading to the need for increased emphasis on fatigue life.

The scale of production in the USA is probably largely responsible for the difference in interchangeability standards. Large components are produced in many different factories, in addition to which multi-shift working is more or less standard. We found, when installing new equipment, that certain systems runs did not correspond to the drawings, the operatives apparently being given a degree of freedom in running cables or pipes between fixed points.

One UK modification involved an external fit on the fin, picking up a number of rivet or bolt positions. With our experience on previous trial installations, the modification was designed with a system of tolerances, and the trial installation was done on a number of aircraft instead of the usual one, so we thought that we had covered the fleet. Believe it or not, this was far from so, and a much more difficult process had to be adopted before fitment to all of the fleet became possible.

To date some 1,000 Phantom modifications have been processed at Brough, many of which were in connection with the introduction of new equipment, or for minor improvements to that already fitted. About 30 were to overcome the fatigue problems being experienced. These accounted for a high proportion of the total man-hours being expended on the project, and also generated a significant shop-floor load.

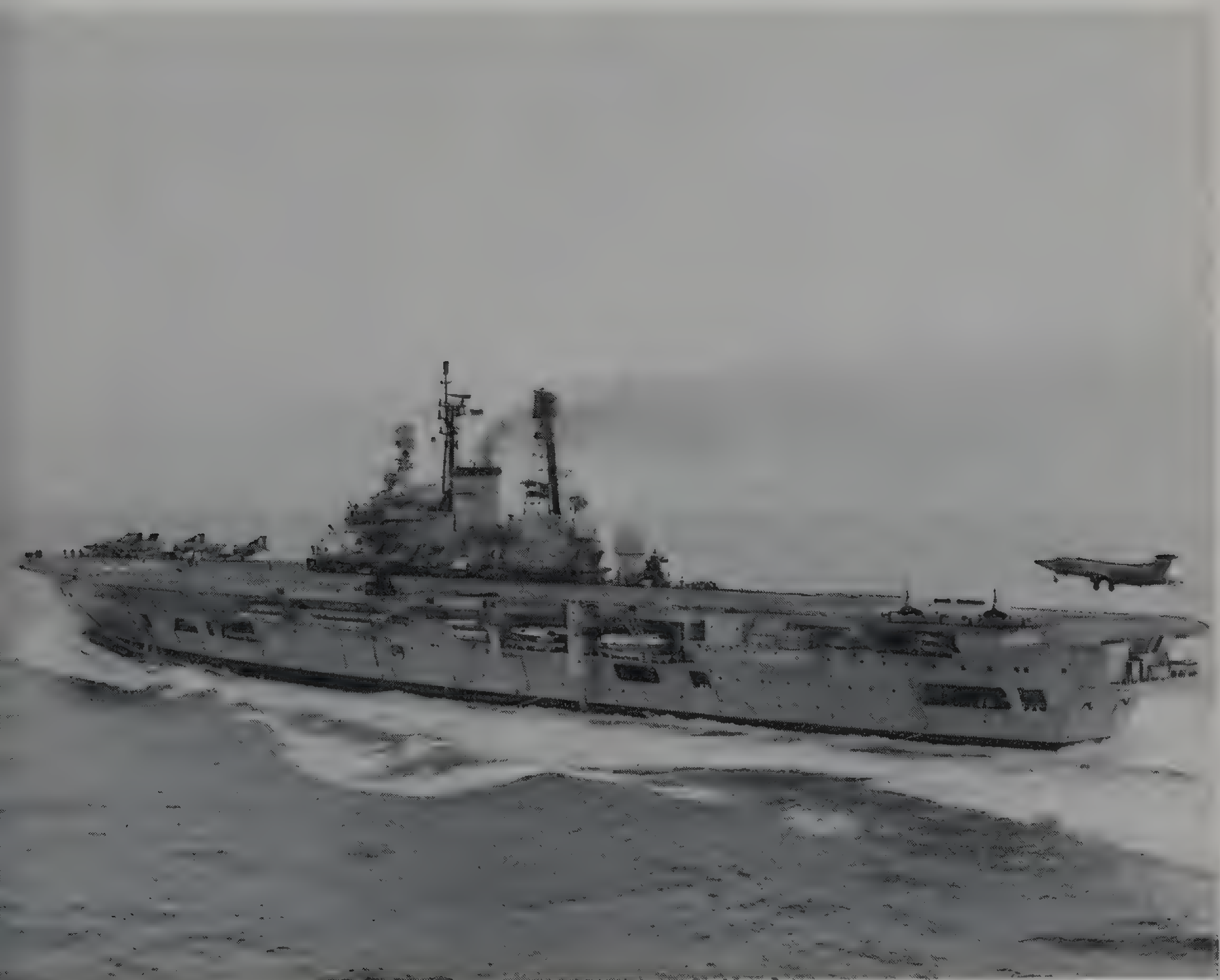
As stated earlier, the original design work for fatigue life on the Buccaneer was done on a rather empirical basis, but this in the main proved to be satisfactory. Subsequently sophisticated methods of analysis and inspection were developed, and these came to be of great value when the Phantom problems arose. Consequential liaison with MACAIR showed the British expertise in a very good light and, if anything, strengthened the relationship between the two firms.

A further aspect of some importance which cropped up was that of cockpit noise. Problems had arisen on the Buccaneer, but this was from the transmission of external aerodynamic noise. Internal noise — from air-conditioning for example — was low, the systems having been designed with this in mind. The strident internally generated noise from these systems in the Phantom was

regarded in Britain as highly undesirable. A rig representing the various elements of the systems was erected at Brough, and operated by the team which had been responsible for the Buccaneer design. They succeeded in producing changes to the design which vastly improved the noise level. Other operators appear to have accepted the system as it existed, but a high noise level can have a serious effect on the crew under certain operating conditions.

With the continuing work-load, both in the design office and on the shop-floor now equalling that for the Buccaneer, apart from the benefits from the trans-atlantic co-operation which have accrued, the role of Sister Design Firm for UK Phantoms has certainly been good business for Brough.

A Buccaneer of 809 Squadron landing on HMS *Ark Royal*, with other Buccaneers and Phantoms of 892 Squadron ranged on deck. *(CN 0246, MOD(RN))*



Chapter 11
Spreading the Load — Outside Work

Up to 1963-64 the entire technical staff at Brough had been engaged on the Buccaneer, but with basic work on the Mk 2 virtually completed, new work had to be found. In the pipeline was the Improved Weapon System Buccaneer, with in addition an Airborne Early Warning programme, the P.139, both of which were being actively chased. Both were suddenly to disappear, with the decision to abandon aircraft carriers from the inventory of the Royal Navy. The result left a large void at Brough.

This situation coincided with the closer intregation of the various companies which now made up the expanded Hawker Siddeley Aviation, for which an overall headquarters organization had now been set up. It was whilst we were seeking self-generated solutions to our problem that we received instructions from Headquarters to deploy design staff to support the Kingston design effort on the P.1154. We were allocated work on the centre fuselage, at a time when great pressure was being exerted on both timescale and cost. This also vanished overnight, but it was followed by giving assistance to Woodford in the initial design of the HS.801 Nimrod, which was an extensive adaptation of the Comet airliner. The task given was the detail design of some of the crew stations and, later, some of the appendages such as wing pylons and the MAD (Magnetic Anomaly Detector) boom which was an extension of the rear fuselage to carry specialized anti-submarine sensing equipment.

After ten years of self-generated saturation and expansion, we were not enthralled at these directives, particularly on three counts. One was that work of this nature employed draughtsmen and the always scarce stressmen, but it did not assist the technical team as a whole. Secondly, detailing from another team's schemes did not make use of anyone's higher creative talents. Finally, there was nothing in it for the Brough shop-floor.

Nevertheless, compliance with the directives was mandatory, so we had to develop a modus operandi. Assessment of the size and composition of the team was relatively easy. The nature of the tasks did not justify detail traffic between the respective chief designers, so the best course seemed to be to place the programme into the charge of a senior section leader and have him do the inter-site liaison. There were some problems which arose which required a higher-level intervention, but by and large the projects went smoothly. The two tasks given to us were not large-scale operations, each in turn using some 45 people out of a staff of 800.

The experience gained was, however, to prove valuable for the future. With the total number of British projects in hand diminishing sharply, but the workload requiring an almost unchanged number of staff, inter-site working rather than the impracticable wholesale transfer of staff was to become a prime feature henceforward.

At Brough the Phantom commitment was building up slowly, although from 1968 onward it more than made up for the diminishing workload, and, more importantly, generated work for the shop-floor. With the occasional peak higher, the combination of Buccaneer and Phantom work, at least up to the time of my departure in 1978, accounted for some 65 per cent of the direct technical staff (staff who book their time directly onto contracted work). Work had to be found for the remaining 35 per cent if they were not to be made redundant.

Of the two original tasks placed on us by Headquarters, the Nimrod work was quite straightforward, but that on the P.1154 was anything but. The centre fuselage was subject to very heavy loads, and engine removal was proposed to be by removal of a large load-bearing tray in the underfuselage and then to drop the engine out. This was totally different from the system used on the preceeding design, the P.1127 Kestrel (and today's Harrier), where the entire wing has to be detached from the fuselage and the engine lifted out. With disagreements on detail design between the two sites, and, in our view, a considerable growth in estimated weight, it was not a happy programme. To make matters worse, I felt that the whole project was premature and overambitious, and indeed some of the operational problems which would have arisen have not been solved to this day. I felt that an operational version of the Kestrel was the way to go, and was relieved when the P.1154 was cancelled and an order for the Harrier placed. Not everyone at Kingston would agree with me, but there it is.

Once the Harrier programme was firmly established, offload work from Kingston became a significant part of the Brough design workload, and also provided considerable employment on the shop-floor. Although not designed at Brough, the Harrier wings have all been manufactured at Brough, with the necessary design support being given from the Brough office. (Harrier II wings are made at St Louis).

It soon became apparent that much greater efficiency would be obtained if detail design and manufacture could be done on the same site, so wherever possible this was to become our practice. Harrier design work allocated to Brough, and which employed 40-50 staff, concentrated on appendages such as wing pylons, the flight-refuelling probe and reconnaissance pod, all of which have been manufactured on site. Design changes to the rear fuselage for the two-seat version were also undertaken, for manufacture elsewhere.

An unforgettable exercise was the design and manufacture, followed by proving, of an air-transportable engine-change gantry. This had to remove the Harrier wing, then change the engine, and finally replace the wing. The gantry had to be broken down for air transport into items of a specified maximum size. It proved to be a difficult task, but was accomplished to the satisfaction of the customer, although the requirements for air transportation did result in a good deal more elaboration than we would have chosen. Whilst the customer was satisfied with the end-product, this was not so with some of the 'high ups' from Headquarters, who had obviously not bothered to read the specification and who greeted our efforts in public with loud shouts of derision.

Harrier support work has remained an important activity at Brough, and has not been confined to design and manufacture of airframe structure. Various electronic sensors and control boxes have been designed and manufactured for production aircraft, and two separate exercises involving design and conversion of individual hack aircraft for development programmes have been undertaken.

The first of these in 1968 modified an early P.1127 Kestrel, XS 693, and instrumented it to act as a flying test bed for developing the Pegasus for the production Harrier. A larger and later exercise (1975-78) was in support of the Sea Harrier programme, which included new radar and avionics. Two two-seat Hunters, XL 602 and 603, were fitted with the new equipment to act in the first instance as flying test beds. On completion of their development programme, they entered service with the Royal Navy as T.8M trainers. They first flew after conversion on 9 January and 17 July 1978, respectively.

Reverting to the late 1960s, another task to occupy both design and shop floor was to produce, with EMI as prime contractor, a reconnaissance pod for the Phantom. This contained an array of cameras, a sideways-looking radar and an infra-red linescan, all to be got into (complete with access panels) an adaptation of the Phantom 500-gallon under-fuselage drop tank. A right bed of nails this turned out to be, and our problems taxed the patience of EMI severely on many occasions. Eventually the task was completed, with apparently satisfactory results. After all this, the pod was not used in service.

With the pod work completed in late 1967, the next major task to arrive was in support of Hatfield on design of the Airbus A300B wing. This saw us responsible to Hatfield, who were in turn responsible to the management of Airbus Industrie in France. Originally our task was to design slats and other components forward of the front spar, and the entire trailing-edge complex aft of the rear spar, comprising a mass of moving surfaces and their support structures. Long-travel flaps with additionally a hinged trailing edge, low-speed and high-speed ailerons, airbrakes and lift dumpers were all involved. On top of the complexity of the design, the staff who were used to the 'safe life' approach to fatigue design had to adapt to the by now standard philosophy for civil aircraft of 'fail safe'.

Some 150 staff were engaged on this project, so it was a major commitment. It soon became obvious that the task as allocated was beyond our resources, so the leading-edge work was transferred elsewhere. Later on, the final detail design of the flaps was placed with Fokker in Holland. This resulted in a crisis, due to different working pratices in respect of balance-out calculations. These form the basis for estimating the detailed loading on components, and had always been done at Brough in a manner with which Fokker were not familiar. It took a high-level international conference to resolve the hiccup before the Fokker programme was able to proceed smoothly, but after this there were no further difficulties.

The flap mechanism, with large track beams and multi-wheel carriages, was particularly tricky to design. In addition, we felt that the Hatfield scheme for the main flap trailing-edge tab would not work. This argument they rejected, only to find at a later stage that redesign was necessary. When the design was complete, it was found to be overweight and slightly overstrength for the initial B1 version of the Airbus, but it so happened to be well-matched to the then-emerging, and heavier, B4 version, which looked like being the major seller. Our proposal to

leave the design as it was was supported by Hatfield, but overruled by Airbus Industrie, so we had to go round again. By 1971 the Airbus exercise was completed and when the wings were finally assembled we were very relieved to find our contribution working perfectly.

The main flaps operated like a Fowler flap, moving aft horizontally along the track for some distance before rotating down for the final movement. The airbrakes consisted of a rotating flap shroud which, when operated with the flaps down, left a large gap between the main wing structure and the flap, spanned by the flap-track beams. I had to go to India to travel in an Airbus in daylight, and chose a window seat with a good view of the wing trailing edge. As we prepared for landing, full flap was selected after which the airbrakes were opened. At this point all hell appeared to break loose, with the flaps supported at the ends of the tracks vibrating madly. I realised that we had not knowingly designed for such conditions, but, such are the safety factors applied during the design process, that the condition is adequately covered.

The development of the situation where several outside tasks could be in hand in the design office simultaneously created quite a few problems for the Brough management. On a purely practical plane, the design office had to be adapted to using five different drawing systems simultaneously. The Buccaneer and other Brough-based projects used the standardized SBAC system. The MACAIR system for the Phantom was entirely different. Kingston used their own system for their products, the Nimrod being an adaptation of the Comet used the old first-angle projection method rather than the more modern third-angle projection which reverses the direction of projection of side and end views. The Airbus also used its own international system.

The Chief Designer, whilst in complete control of the indigenous projects, has a different role to play in respect of those of outside origin. He has a duty to allocate resources, and to ensure that the outside agency is satisfied with the quality of the work and progress being made. However, as mentioned previously, it is apposite to appoint a project designer, of seniority appropriate to the scale of the task, to run the job and liaise with the originating designer. As the multiplicity of projects grew, this arrangement was inadequate, and genuine project management had to be introduced where, in addition to the project designers, project engineers were appointed to oversee contractual matters, programmes and progress together with the necessary outside liaison. At the same time, they had to keep the Chief Designer informed so that he could intervene when necessary. Once it was understood, this dual arrangement of project designer and project engineer/manager worked well, and it has become a permanent feature.

The multi-site working of the type described is in these days the norm, often with international links. Back in the mid-1960s the fairly gentle run into this procedure at Brough proved to be a very useful if sometimes painful experience. The cross-fertilization between different design teams can do nothing but good, and the management problems which arose in the early days are now understood, and the pattern for the future clearly set. Experience on individual projects has sometimes been happy, but sometimes painful. In the latter category, but not directly concerned with the work itself, was our participation under Hatfield in the original programme for the 146 airliner. The task was the

design of the front fuselage structure, a not inconsiderable task which used up to 35 per cent of our entire force of draughtsmen and stressmen.

It was almost invariably a feature in taking on this type of outside work that the tasks on offer required more labour than was readily available, in addition to which the programme set by the originating site was in any case difficult to achieve. If it were otherwise, they would not be putting the work out. The result was that one had to take some staff off one's own work, and then exert pressure all round.

From mid-1972 until the autumn of 1974 we struggled on, and, as the scheduled date for completion approached, the pressures on the staff employed were increased still further. At the peak of this final rush, the Hawker Siddeley Board, due to economic and political factors which had arisen, suddenly cancelled the project. We were instructed to ship all drawings and data down to Hatfield. To the technical staff union, TASS, this implied both a redundancy situation and a serious and probably permanent diminution of the UK share of the civil air transport market. This was a situation which they were not prepared to accept. Their intention was both to prevent all our output being transported to Hatfield, and at the same time to mount an intensive political campaign to have the project reactivated. For this they enlisted the support of all the unions to represent the entire factory work-force. Canvassing on a large scale, they wrote letters to virtually everyone conceivable from the Prime Minister downwards.

Of course management knew that something like this was brewing, and expected that an attempt would be made to lock them out of the factory, and contingency plans against this were made. This action did not in fact happen, but overnight the unions barricaded the whole design office area, ostensibly to prevent the drawings from being removed. The whole miserable affair was compounded by the situation where a multi-union committee had to be dealt with, and it took six weeks before normality was restored, during which I was locked out of my office. Sad to say, there was no change to the 146 position although, as is well known, it was very successfully revived some years later.

The type of situation which arose is particularly difficult for management. It is relatively easy to take violent action and flatten the situation, but this can prove counterproductive in the longer term. A patient and tolerant approach to settle a dispute without subsequent rancour is more difficult, and tends to develop frustration among the loyal members of staff who refuse to participate in the dispute. However, such an approach must pay off in the long run, and this was the case on this occasion.

The dispute described was not the province of the management of the site on which it occurred, nor even that of the site who had generated the work. It just shows how complicated life can be at times, and I hope that this particular occurrence will remain unique.

A much happier task was our participation in the Kingston-originated P.1182, subsequently named the Hawk. At the start, it was an unsolicited proposal for an advanced trainer, the brainchild of small group of people who had been involved on Gnat and Hunter training aircraft. Initially their representations to the Government fell on deaf ears, but suddenly the position changed.

The Anglo-French Jaguar originated from a Breguet design for a supersonic trainer, and it was still intended for this role when in 1966 Breguet and the

A Nimrod and a Harrier in company with Buccaneer XV 350, September 1969.
(BAL 24545)

A Hawk with Sidewinder missiles. *(783686A/B.Ae.K.)*

British Aircraft Corporation joined forces on an international venture. Within the United Kingdom two factors intervened. Financial pressures to reduce costs were being applied. It was realised that fuel cost was a significant item in the total bill, and to replace a twin-Adour-engined aircraft with reheat by a single-Adour-engined and unreheated aircraft could make a significant difference in this respect, without adversly reducing effectiveness. At the same time, alarm was being expressed in some quarters on the front-line strength of the Royal Air Force, for which diversion of the planned Jaguar buy from the training to a front-line role would give a useful boost.

As a result a new requirement suddenly emerged for a single-engined training aircraft, and Hawker Siddeley Aviation and the British Aircraft Corporation found themselves in intensive competition to obtain the order. Fixed price, and targets for maintainability and reliability with financial penalties for non-compliance, formed part of the negotiations. The hard bargaining which ensued finally resulted in the contract being awarded to Hawker Siddeley Aviation, and the P.1182 moved from being an unwanted brainchild of industry to become an active official project.

During this phase, a committee chaired by John Glasscock, then Director and General Manager of the Kingston factory, and including representatives of other sites which might be involved with the project, met at Kingston to review both the design and implementation of the task. I was the member representing Brough, and we were allocated the design of the wings, fin and tailplane. Bearing in mind my strong desire to have design and build on the same site, it was a bitter disappointment to hear manufacture of the wings allocated to Hatfield, a disappointment partially offset by the most enjoyable collaboration with Charlie Kiff, the Hatfield production engineer. Before the build programme began, there was a sharp increase in the Hatfield shop-floor load, as a result of which build of the P.1182 wings was after all allocated to Brough. All Hawk wings have been built at Brough, together with the fins and tailplanes. Part way through the programme, parts of the centre fuselage also became a Brough manufacturing responsibility. Between 1971 and 1974 the Brough design effort on the P.1182 Hawk used 20 per cent of the total staff available, and a much higher proportion of the draughtsmen and stressmen, and was certainly a major commitment.

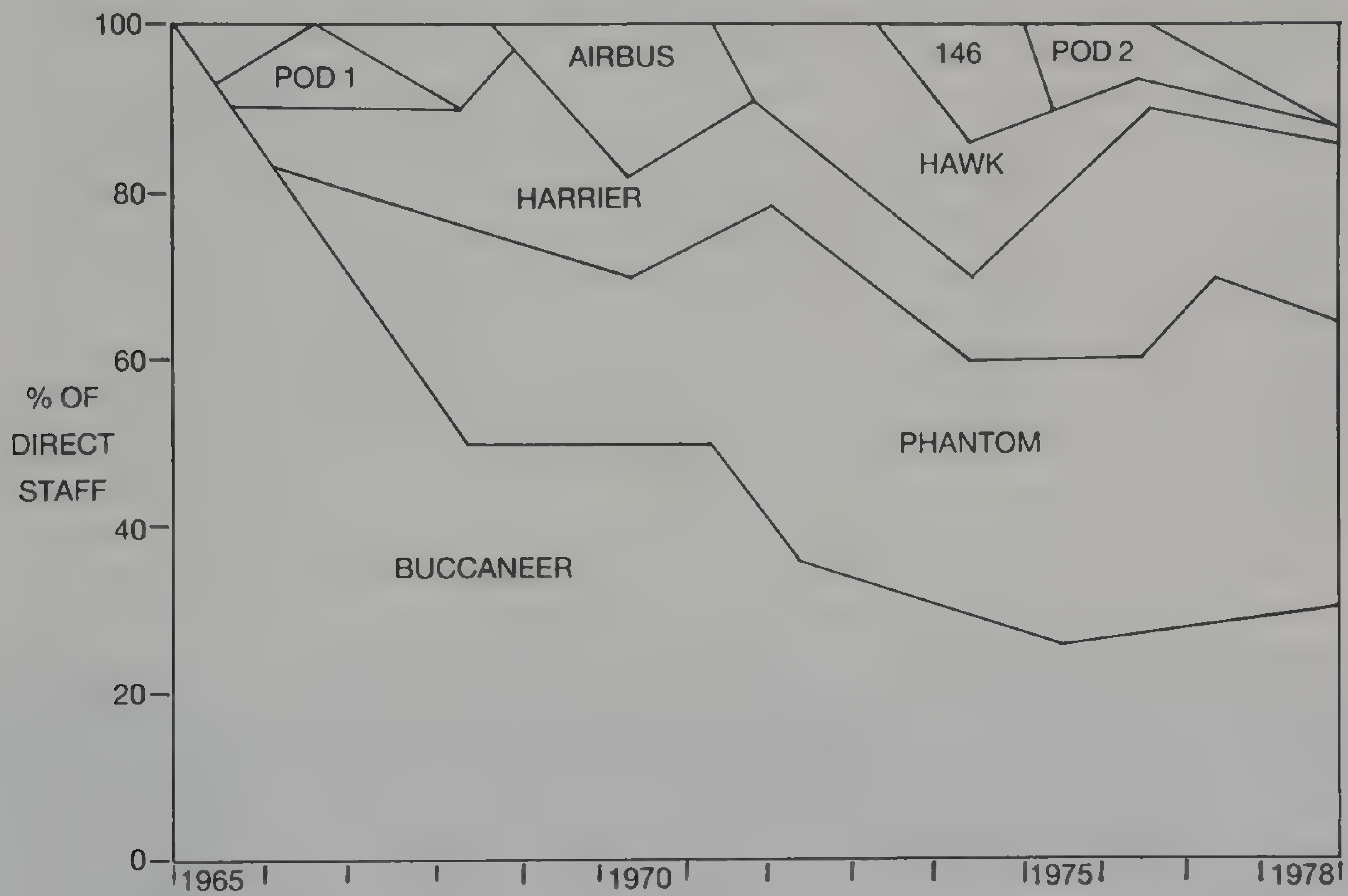
It rapidly became obvious that the Kingston thinking on design was distinctly advanced, and caused not a few problems both in design and production. At one progress meeting, when some problems were being discussed, John Glasscock asked why all this fuss on a simple aircraft? I interjected that, whilst the equipment was relatively simple, the airframe was far from so. John looked surprised but appeared to accept the statement. The subsequent record of the Hawk proves that Kingston were on the right lines from the outset.

Inevitably, as final assembly dates loomed nearer, the build progress of the wing became increasingly critical, with delays being incurred. One problem which was affecting the assembly of major components of the wing was to allow adequate clearance with the undercarriage during retraction. By good fortune one of our young technical geniuses, Stephen Hall, had conceived and developed a new concept for a computer-aided design system. At that stage this CAD programme could only manage a problem of limited size, but fortunately it was adequate for this particular problem. The matter was resolved in a couple of

days, and assembly of the wing went ahead. Without this newly developed CAD system, the whole Hawk programme could have been set back several weeks at a not insignificant cost.

One of the factors influencing cost is the number of parts per component. This is not only dependent upon the designer but also on the machine tools and equipment available on the shop floor. To some extent, as a result of their better production runs and facilities, the American record in this context was much better than in Britain. We had been trying to counter this situation for some time, but fully understood the management directive to submit our Hawk tail unit design for independent audit. Happy to say, it passed with flying colours, but the exercise is a good example of inter-site working for the good of the whole.

Eventually the first Hawk was assembled at Dunsfold, and prepared for flight. As part of the excellent relationship which had prevailed throughout, a team representative of all sections of the Brough factory who had contributed to the programme were invited to Dunsfold to witness the first flight. We assembled in our Dove and flew down to Dunsfold, arriving mid-morning. It was one of those



The allocation of direct technical staff by project.

days when minor snags arose in succession, such that it was early evening before the flight took place. It was more than time for our return flight to Brough, so having seen the flight, we missed the party, taxiing out with Duncan Simpson still in the Hawk cockpit with the engine running. From what we had seen, however, it certainly looked as if success for the Hawk was just around the corner.

Design support for the Hawk has continued at Brough over the years, albeit at times on a relatively small scale, but at the time of writing, assumption of total

responsibility for the two-seat Hawk is in the pipeline. Together with the work on the Pilatus PC.9 this will place Brough in a major role in the trainer business for some time to come.

Over the years, Brough designers have studied possible role pods for fitment to aircraft for both reconnaissance and electronic-warfare duties. Responsibility for any such projects in terms of sponsorship lay with the electronic branches of the Ministry of Defence, and not with the airframe branches. Thus any project which went ahead would be via the electronic branches, and they insisted that an avionics firm which was supplying some of the equipment should be the prime contractor responsible to them, although in most cases they would subcontract out that part of the task which was normally the province of an aircraft manufacturer. It was this arrangement which found us as subcontractor to EMI on the Phantom reconnaissance pod. Having studied possible electronic-warfare pods, and made proposals over many years, when it was finally decided to undertake an advanced pod in the United Kingdom rather than indulging in yet another overseas buy, the prime contractor was one of the major British avionics companies (GEC Stanmore, later Marconi). Brough found itself responsible for the pod and its cooling systems, and for the manufacture of the basic pod for final equipping with its electronic gear. This was a substantial task both in design and shop-floor activities over several years.

I have attempted to give a cameo of how a single project and independent organization reacted to the changing circumstances of fewer and longer-term projects, concurrent with the evolution of many of these sites into the single large organization of British Aerospace, and to relate some of the 'baddies' and some of the 'goodies' which were experienced during this evolution. It is not only on aircraft projects that integration of activities has taken place. Wind tunnels and test facilities are used by the organization as a whole. The evolution at Brough of a comprehensive electronic systems rig now provides, on a nation-wide basis, a tool for developing the advanced systems which will appear in next-generation aircraft.

The presentation by N. V. Barber, Director and General Manager, Brough, on the author's departure. *(BAL 28556/1)*

Chapter 12
Travel Abroad

Travel abroad on business is by no means an enjoyable semi-holiday but consists, in the main, of the hassle of overcrowded airports, incarceration in aircraft for long periods, and prolonged views of the insides of hotel and conference rooms. The only pleasure arises from some of the human contacts made. For instance, I travelled all the way to Kuala Lumpur and back and, in an entire week there, apart from travel between hotel and meetings, only left the hotel for a couple of hours during the afternoon of the last day there.

Exceptions do occasionally arise, and one was a visit I paid to South Africa in 1968, following the order of Buccaneers for the Royal Air Force. Several of the features we were proposing for the RAF variant had been applied to the South African Buccaneer Mk 50, and I suggested to the Managing Director, Capt E. D. G. Lewin, RN Retd, that a visit to assess how they had worked out in practice might be opportune, and he readily agreed.

Arrangements were made by Hawker Siddeley South Africa, who were located in Johannesburg with Jack Davidson as Chairman and Air Vice-Marshal Ted Jacklin, late of the Rhodesian Air Force, as Managing Director. It was Ted who had masterminded the South African Buccaneer deal, in the course of which he had become a bosom friend of Capt Lewin, who rejoiced in the universally used nickname of 'Drunkey'. Two other key figures had been Admiral Bierman, known as 'Boozey', and one of our agents, late of the South African Air Force, Brigadier Wilmot, known as 'Whisky Willie'. What happened when these three got together was a matter for alcoholic speculation.

This was my first overseas trip where there was an agency to look after me and make all of the arrangements, and what a difference it made! Disembarking from the VC10, I was met by Alan Bell, installed in the President Hotel, introduced to the office, and then given the luxury of 24 hours to recover from the overnight journey and to acclimatize.

The following morning I was taken to the South African Air Force Headquarters in Pretoria to lecture on potential Buccaneer developments, followed by a lunch as the guest of Brigadier Robb, Head of Tactical Group. Somewhat lubricated I was then transported with the base commander, the unforgettable Colonel Wellington, to Waterkloof airfield where 24 Squadron with its Buccaneers was based. The afternoon was spent in very open discussions with various squadron personnel, to be followed by a reception in the Officers' Mess. This was hosted by Colonel Wellington and various other dignitaries, but I was

besieged by young and enthusiastic junior officers talking away whilst unknown quantities of alcohol found their way down my throat. The end of the reception was announced and on exit, somewhat befuddled, I realised that the youngsters had monopolized my attention, and that I had virtually ignored the senior hosts. As most of them had been at the lunch, maybe this was what they had wanted and hopefully they were not offended, but I felt awful about it. I subsequently learned that the custom was to give either the lunch or the reception for visitors, but I was honoured with both, to the detriment of my liver and my decorum.

During the week I went to pay a courtesy call on the Head of the South African Air Force, General Jimmy Voerster, with whom I had become friendly some years earlier. The staff officer conducting me in said that things were very hectic that morning, and would I only be ten minutes or so? However, Jimmy wanted to talk and there was nothing I could do about it. It was about an hour before I finally emerged, keeping my face averted from the staff officer. Apart from my planned meetings with Air Force personnel, and a visit to the recently formed Atlas Aircraft Corporation — who, among other things, were to undertake major maintenance and overhaul on the Buccaneers — I was diverted to a few clandestine meetings with national and political figures.

Thanks to good planning by the Hawker Siddeley office I had a free weekend, and Jack Davidson arranged a trip for me to the Kruger National Park game reserve, with his son-in-law, daughter Meryl and their small daughter as escorts. Rather than have us suffer the rigours of the rest camps in the reserve, Jack arranged for us to stay in a hotel not far removed from one of the entrances into the park — Bushman's Rock if I remember correctly. In retrospect, this was a mistake as we wasted a lot of time in transit, not to mention the aborting of the final day on account of the little girl being bitten by one of the peacocks in the hotel grounds. Nevertheless, it was a great experience, and once again showed that television or film programmes viewed after one has seen the real thing in the flesh have a different dimension.

Apart from seeing the terrain in which wild game lay, zebras, wildebeest and many giraffe and varieties of birds were seen in profusion. We got adjacent to a herd of elephants, and waited a long time to get a view but the only one we saw was a lone baby in the bush, added to which the lions were elsewhere. We did, however, stop to warn an oncoming car that a large snake was stretched across their side of the road, in return for which they told us of a leopard asleep on the lower branch of a tree right beside the road. This is a very rare sight and, finding it, I lowered the window and made leopard-type noises. The animal, well fed, slowly awoke; finally it looked at us with disdain, and I took a series of photographs during the proceedings. In concentrating on finding the leopard it emerged that, just before reaching it, we had gone past our planned turn. When we realised this we were 20 miles or more off course, and had to get out of the reserve before the gates were closed at dusk. Comparing notes at the hotel that night it emerged that our navigational error had missed us the sight of a lion kill.

Throughout the trip I had seen something of the domestic luxury of the professional whites, and something of the conditions then enforced on the blacks in the big cities. Driving across the veld to the game reserve we passed one of the shanty towns on the outskirts of the city; later we saw some of the native settlements out in the country, after which the shanty town didn't look too bad. Trying to understand the sociological and economic problems of the country,

one couldn't help feeling that the pictures presented by the media were far from the truth, but had caused a polarization of views and attitudes which had exacerbated the situation, rather than led to any improvement.

Partly as a reward for the extramural duties I had undertaken on their behalf, Jack Davidson arranged a trip to Cape Town for me, with Whisky Willie who lived there to act as my host. Arriving in a Boeing 727 with very low cloud and in pouring rain, I was met by Willie, escorted to a delightful country hotel in Newlands, and then on to a dinner party which Willie had organized and which included a strong SAAF contingent. In conversation with the Head of the Maritime Group, Brigadier Geof Krummek, I told him that I had brought my slides with me and offered to give a talk. This he accepted, and made arrangements for the following afternoon, and in return offered me a helicopter trip around the Cape area.

The following morning was blue skies, sunshine and calm, quite unlike the previous evening. Willie had a business appointment that morning so his wife, Alison, drove me to the terminal of the cable car to go up Table Mountain with a time set for her to collect me and take me to Maritime Group Headquarters. The view from the top of Table Mountain on such a clear and fine day was magnificent. My talk in the afternoon seemed to go well and, on emerging into the open air, there stood my helicopter. I had permission to take my camera, and obtained some splendid pictures of both the Indian and Atlantic Ocean sides of the Cape, in addition to views of Table Bay and Cape Town.

The following morning was again blue skies, but it was blowing a severe gale such that neither the trip up Table Mountain nor the helicopter trip would have been possible. During the morning Willie took me for a drive down the Cape of Good Hope, which is in fact a long narrow promontary running south from Cape Town, with Table Bay on the Atlantic side to the north.

We drove down the east side, calling on Boozey Bierman in his headquarters at Simonstown, and eventually crossed the Cape to return northwards on the Atlantic side. The Indian Ocean to the east had been completely calm, but the effect of the gale on the Atlantic breakers had to be seen to be believed.

My flight to Johannesburg was scheduled for that evening. Willie decided to take an afternoon nap on his bed, and I was left to rest on a couch in the lounge, Alison being out somewhere. As it became dark, an icy polar blast descended on Cape Town — apparently a well-known phenomenon — and in an unfamiliar room in the dark I was unable to find either the light or heating switches, and I was frozen. However Willie appeared on time to take me to the airport and, with an overnight stop in Johannesburg, I returned home the following day. Thus ended the rare combination of a useful business trip and a semi-holiday. If only South Africa had remained as it was, or progressed in the right direction, I would have very much liked to visit again, but this was not to be.

Between 1981 and 1984, in connection with lightweight fighter business, in addition to several short trips to Sweden, I paid several visits to India. These varied in duration from three days to two and a half weeks. The normal point of arrival and departure was New Delhi, where British Aerospace had its main Indian office, at that time headed by Ian Brimson, and where the odd meeting was held at the Indian Ministry of Defence.

Most of the business to be done was down south at Bangalore, where British Aerospace had an office headed by Alan Milsom. The Indians had formed an

organizing committee for their LCA (Light Combat Aircraft) chaired by Dr Rao Valluri, then Director of the National Aeronautical Laboratory in Bangalore. Included on the committee were Raj Mahindra, lately Managing Director of Hindustan Aircraft at Bangalore, Arun Prasad from the Gas Turbine Establishment, and Professor Narasshima, all Bangalore-based, and Vivek Sinha, Controller of Research and Development, who was based at the Ministry of Defence in New Delhi. Meetings with the committee were normally held at the National Aeronautical Laboratory, with a collection of specialists also present. The reporting chain was to the Minister of Defence via his Chief Scientific Adviser, latterly Dr Arunachallam.

As individuals the Indians were delightful people to associate with, although in a group in formal session they could at times be rather prickly and procedure-bound. I put their considerable sense of humour to the test one day when we got into a bureaucratic tangle, and I dared to say, 'Let's put it this way, we taught you bureaucracy, but you have developed it'. This in fact brought the house down, and we moved on with another crisis at least diverted.

Indian airports are in a class of their own, with most of the 700 million inhabitants apparently all trying to travel at the same time. Bombay International Airport in the middle of the night, when most of the international flights operate from there, is literally solid with people. One can move about only by using one's luggage as a battering ram. Delhi is little better. The Indian enthusiasm for documentation and rubber stamping can cause constipation in the various channels. One has to develop a forebearance, and budget for the time taken. Internal flights, such as between Delhi and Bangalore, are often over-subscribed. Unless you have a guardian angel, such as a local agent, double-confirming your booking, you can easily find yourself stranded on checking in. To add to the discomfort, the internal airlines operate on very fine margins. It takes only a slight mishap to throw schedules out by many hours, without notice. Overall, travel into, out of and within India can be an ordeal which I would rather do without, but it must be said that, once I was aboard an aircraft, everything was splendid.

When you finally reach your destination hotel the service is out of this world, and the modern hotels the equivalent of those anywhere. I gather that Government Guest Houses and some of the more provincial hotels do not come into this category, but I did not have to experience them.

If you have to remain operational throughout, great care of the stomach is essential. Drink only bottled mineral water, avoiding anything from the tap; eat no ice cream or raw fruit, no matter how tempting; be very discreet in the choice of main courses, and take the pills regularly. Such discipline soon becomes monotonous, but it must be observed, even though I have found that by the end of a week it was becoming increasingly difficult to sustain. One other rule which I followed was that, at the many buffet-type receptions, avoid the anonymous meat-based dishes laid out and stick to the vegetarian ones.

The Indian scene is fascinating but, at the same time, mind-boggling. The media presentations can give no true picture of the amazing extremes of wealth and poverty, and the incredible application of dirt-cheap manual labour to tasks which we have had mechanized for a century. A trip through the countryside between towns shows living conditions in the settlements quite unimagined, and

gives some understanding of the life accepted by the itinerant labourers who move with their 'tents' between jobs.

My regular port of call in Delhi was the Maurea Hotel. On my first visit, like everywhere else in Delhi, it was being extended in readiness for the forthcoming Asian Games. A huge hole had been dug, and the labourers with their families were encamped on adjoining waste ground, both of which were visible from my window. During the day the women with loads on their heads carried material to and from the hole, exchanging loads half-way down. In the evening the men would go in search of brushwood for their cooking fires.

In the course of many visits to India I did manage to have two free weekends. One was in Delhi, during my first visit to India. Saturday was spent seeing the sights of New and Old Delhi, which included the Red Fort which has ex-British Indian Army quarters running alongside, provoking nostalgia. On the Sunday, as traditional tourists, we had chosen to visit the Taj Mahal at Agra. Funking the rigours and uncertainty of public transport, my companion Arthur Barnes and I hired a chauffeur-driven Mercedes. The Sikh driver, Ranji Singh, was quite a character. Apart from his considerable knowledge, which he passed on to us at frequent intervals, he took a deep pride in the people he had driven, who included Sir Frederick Page and 'The Long One'. Apparently his tongue could not master the name Ivan Yates.

The journey through rural India was an education in itself, both in terms of native life and traffic behaviour, which at times was positively suicidal. On reaching Agra, Ranji hired an expert guide and the tour began. The Taj Mahal was crowded and magnificent, but the wondrous sight is when the marble glows by moonlight, which day trippers like us do not see. We then moved to the adjoining Red Fort (no relation to that at Delhi), at which I was quite astonished. It was vast and in parts very ornate. In its day it housed the emperor and ten thousand supporters, and was remarkably well-preserved.

I have described as suicidal driving tendencies in the open country. Traffic is no less disconcerting in the towns. It includes sacred roaming cows, motorized rickshaws, overladen carts and a million bicycles. In one of the busiest Bangalore streets we encountered three cyclists travelling along positioned at the three corners of a large roof truss, taking up most of the road. At all times the motorized traffic weaves and dodges, with considerable aggression and little discipline. I was quite convinced that it was only the poor acceleration of the predominant car, the Ambassador — an Indian-built version of the old 1948 side-valve Morris Oxford — that prevented carnage.

For the free weekend which cropped up during a spell in Bangalore we planned to stay in a tented camp adjacent to the jungle. As a meeting was called for the Saturday morning it was past noon when we set off in extreme heat in a convoy of three cars. One car repeatedly broke down, so we finally abandoned it and with some discomfort crowded the whole party into the remaining two. Passing the city of Mysore, we eventually reached the camp too late for the scheduled Land-Rover trip into the jungle. We did go on a curtailed trip but, apart from countless birds and monkeys and the odd deer, we saw nothing. The other half of the party did meet head-on a rogue bull elephant on a narrow track, and had to do some smart reversing. To compensate for this, the early-morning trip down the river in a coracle to bird watch was postponed, and we boarded the Land-Rovers again and headed into the jungle. We had to clear

trees lying across the track which had been uprooted by elephants, and there were other definite signs of their proximity but we saw none. However, we were taken to a nearby working elephant camp, were the animals were being prepared and then taken off for lumber work. It was fascinating and at times unnerving to witness this at close quarters.

Back to the camp and off for the postponed coracle trip. Needless to say, one of the two coracles had sprung a leak, and we all had to crowd into the other. Packed together, such that we could not move, the full noonday sun striking off the water did us no good at all, and most of the birds which we should have seen in the early morning were conspicuous by their absence. We did however, on the return journey see the rogue bull elephant of the previous day, who had emerged from the jungle to feed and water himself by the river. We landed at fairly close quarters to study him, leaving before he started to take exception to us.

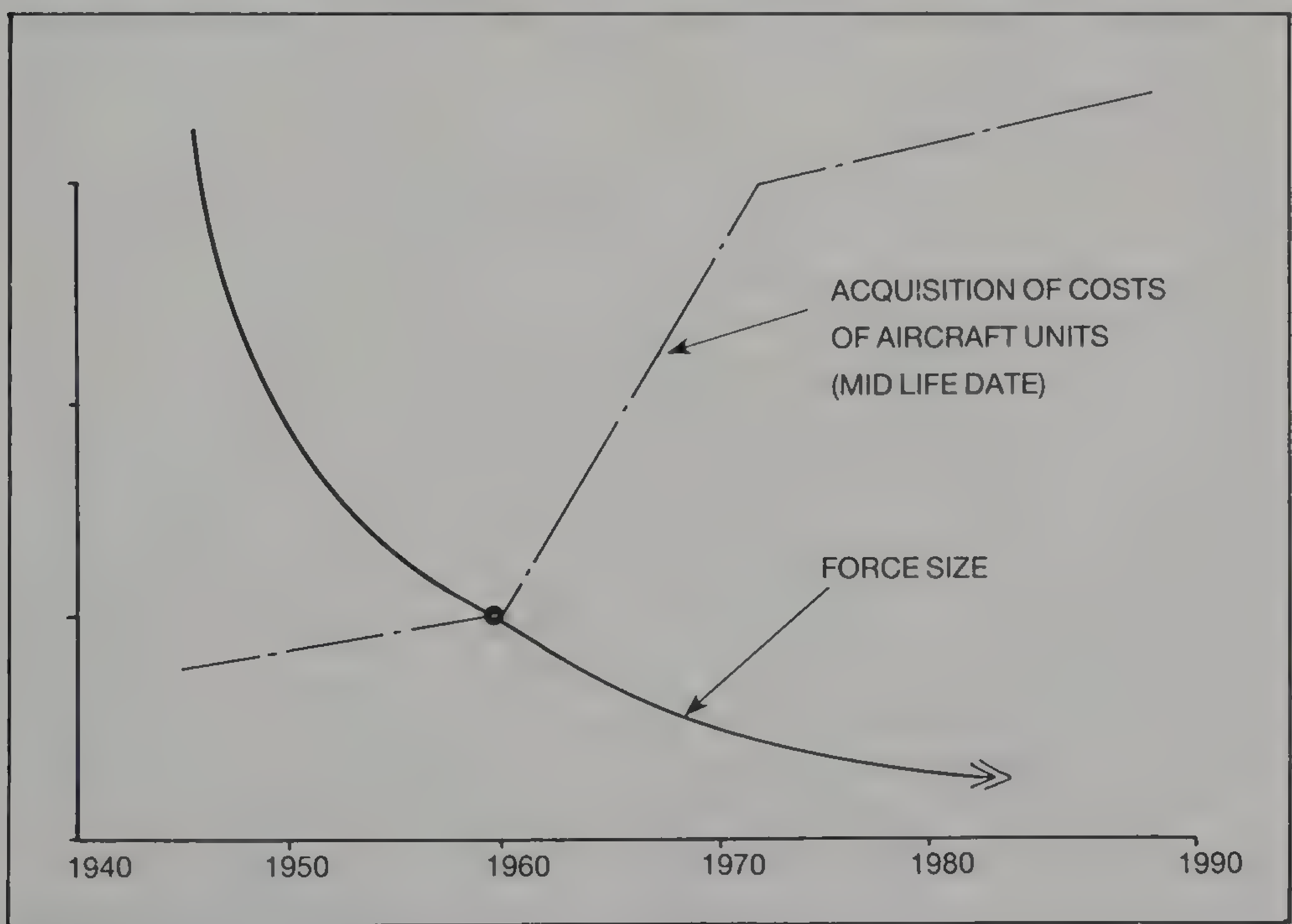
It was now time to return to Bangalore and resume work. In spite of the failure, as in South Africa, to find some of the animals, the assimilation of the nature of the jungle terrain and atmosphere is something always to be remembered.

Chapter 13
Looking to the Future

So far I have concentrated on the past. This is a relatively safe thing to do. Interpretations and opinions may vary, but the facts are established and inviolate. Looking to the future involves committing oneself to a particular view at a particular time. At best this dates the time of writing, and with the order of developments which take place in the aerospace industry, it can prove to be seriously in error.

Neverthless, as a very high proportion of my working life has been spent specifically looking to the future, the temptation to put forward some views, not only on the application of developing technology but also on the methods of selecting and actioning new projects, is impossible to resist.

My observations concentrate on fighter-bomber aircraft, although other aircraft involve similar problems. Certainly a basic problem is cost and affordability. An accompanying diagram shows the startling decrease in the number of front-line aircraft in the air arm of a typical major power from the end of the



Typical force size and cost.

Second World War to the present day with a factor of between ten and 50. At the same time, even assuming a constant monetary value, the cost of purchasing this reduced fleet has increased nearly fivefold. It has been said that, if this trend continues at the same rate, soon only a single aircraft can be afforded every decade. Of course, the modern aircraft is many times more effective than its counterpart of 40 years ago, but, even so, there must be a minimum size of force which can undertake the tasks required of it.

This considers acquisition cost only. The cost of maintaining and operating the aircraft is also a major factor, and one must not forget the ever-increasing cost of expendable weapons. There has been an increase in cost of between 10 and 25 times for air-to-ground weapons and at least ten times in those for air combat. It would be futile to fight a war with an aircraft fleet but with insufficient weapons. The attainment of the correct balance of expenditure between the vehicle and its weapons is of considerable importance when a limited budget is imposed.

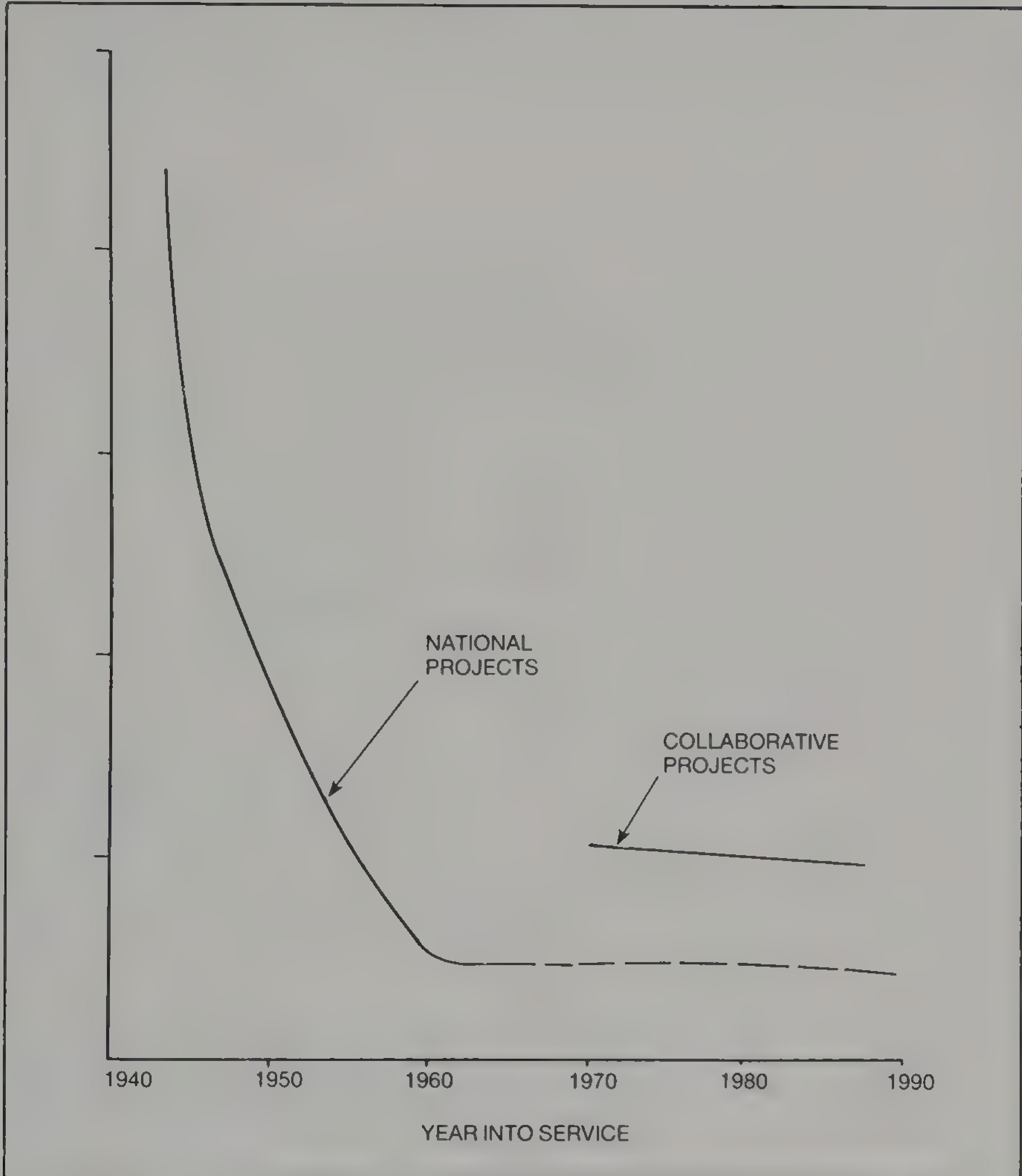
The area of the 'ilities' in connection with life-cycle costing is one involving the operator as well as the supplier. Reliability, maintainability and survivability are all at stake. Survivability can be to some extent enhanced in the basic design by the suitable siting of equipment, either by the adequate separation of duplicated equipments or by installing items where they can act as shielding for the aircrew. Beyond that, it means more weight for armour and other protection, with either a loss of performance or higher cost for the same performance, against which peacetime costing militates, and a technical tight-rope has to be walked.

The enormous increase in aircraft complexity in 1955-70 led to an 85 per cent increase in the defect rate, and man-hours for maintenance per flying hour were more than trebled. The combination of these two factors caused the operators great concern. The pressure which they then exerted has led on the succeeding generation of aircraft to a 35 per cent reduction in the defect rate and some 45 per cent improvement in maintainability. To some extent, maintainability is directly related to reliability, but there are other factors. Ease of access is one, but with the high packing-density of the modern high-performance aircraft this can be difficult to provide. If one can predict which equipments are to be the most unreliable (and by analysis of records of current in-service aircraft some sore thumbs may be predicted) it helps to instal them in the most accessible positions. Certainly designers have had the problems firmly implanted in their minds, and are endeavouring to improve the situation further. The abandonment of fixed-period removal of equipment for inspection and overhaul has greatly reduced the maintenance load. Much is now only removed if it fails, but this can be an acceptable situation only if the reliability is sufficiently high.

Reliability of equipment can arise partly by good detail design, but the only sure way to achieve and establish it is by a severe testing programme in the early stages of development. This must mean either before the aircraft programme has evolved, or very early in its programme at a time when the spend is traditionally at a low rate. Equipment testing of this nature is expensive, and it is very difficult to obtain the funding required at this stage of the programme, so we have to live in something of a paradox.

Improved 'ilities' are important not only for reduced cost of operation in peacetime but become force-multipliers in wartime, because they result in more aircraft being available. Attempts have been made to assess a breakeven value

of expenditure on the 'ilities', with little success. Today however, it is common to have defined numerical values for Reliability and Maintainability specified in aircraft development contracts, with financial incentives for beating them.



Production value/launch cost.

The foregoing highlights problems facing the operator, in the solution of which the supplier has an important role to play. The supplier, however, is an industrial organization, and as such is expected to produce a return on the capital invested. Two factors have militated against this: the vast increase in the launch cost of the modern combat aircraft, and the much smaller production run. If new engines and new equipment are installed in a new airframe, launch cost is likely to be about 200 times the cost of a single production aircraft. If the engine is a derivative of an existing one the factor might reduce to 160, and if both engine and equipment are straightforward derivatives the factor can come down to around 130. With a national order not likely to exceed 200, the adverse economics are obvious.

In the accompanying diagram the data have been somewhat simplified. Launch cost is calculated only up to the first flight of the first variant, although

the production figure is that of the whole production run. It does, however, give a true picture of the trend which has taken place. The current ratio of production value to launch cost is only one-quarter of the ratio for 1950.

It is against this background that international collaboration for any major project has become virtually inevitable in an attempt to restore the balance. As can be seen, it has improved the ratio by some 100 per cent, although it is still well below the historical value.

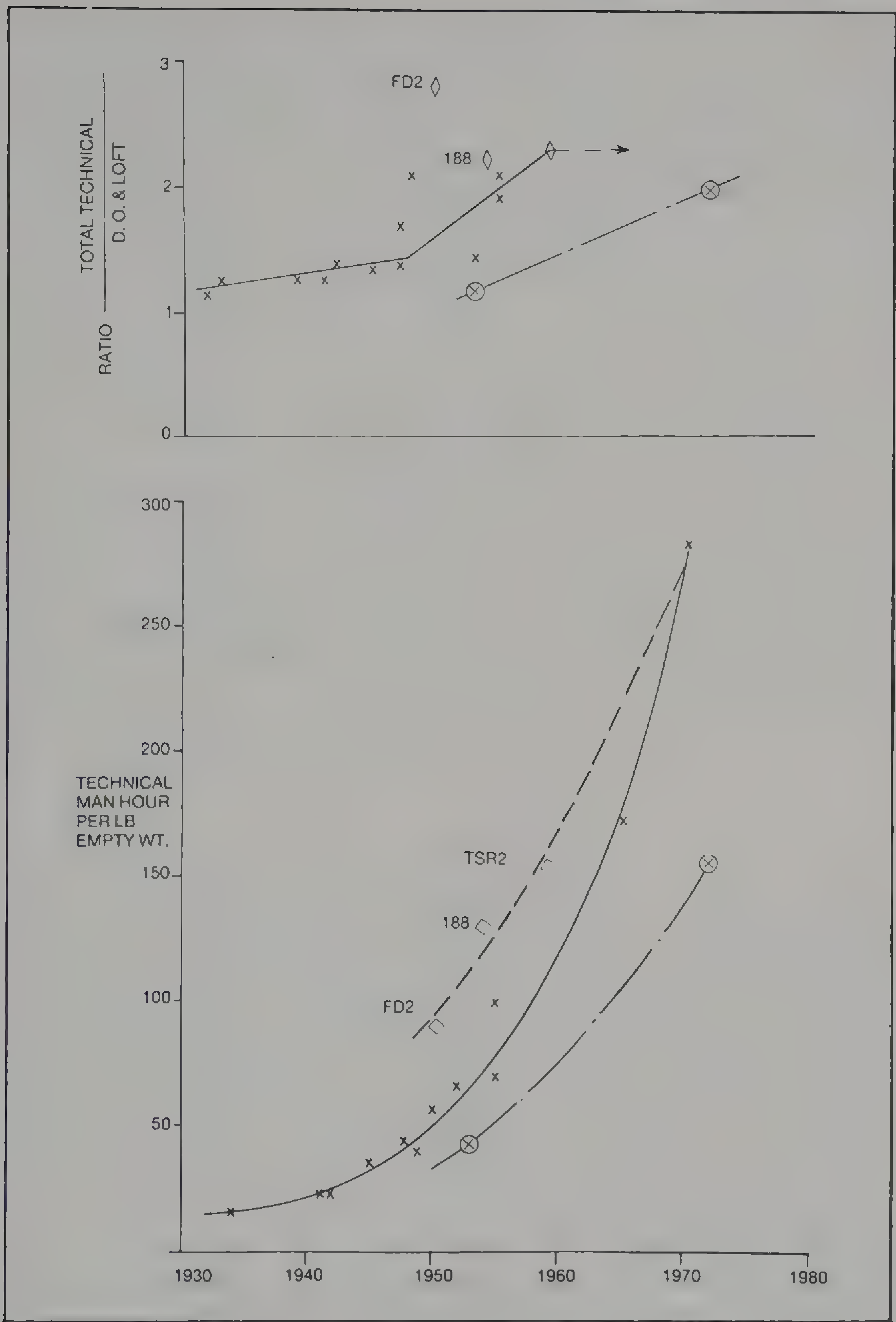
Review of past costs

In an attempt to draw attention to the trend which has taken place and to try to identify some of the reasons for it, in 1979 I analysed data on a large number of aircraft projects extending over the timescale from 1933 to 1970. The dates used are those for the placing of the initial contract, rather than the more conventionally used first flight or entry into service. I thought that this better represented the standard of technology intended, and hence the difficulties which might be encountered during the development phase. It also enabled me to include some experimental aircraft which of course did not go into service. I selected as the relative aircraft parameter the basic empty weight, rather than one of the more sophisticated parameters used today. To some extent this was a practical necessity, as it was the only suitable information available on the earlier types, but it did also seem a reasonable parameter to use.

The types reviewed encompassed from the 1930s classic wartime aircraft such as the Hurricane, Spitfire, Mosquito, Wellington and Halifax, from the early 1940s the Meteor and Vampire, from the late 1940s the Hunter, Swift, Javelin, Canberra, Valiant, Vulcan and Victor, from the 1950s the Saunders-Roe SR.53, Bristol 188, Fairey FD.2, Buccaneer, Lightning, Phantom and TSR.2, from the 1960s the Jaguar, Tornado, Harrier, F-14 and F-15, and from the 1970s the Hawk, Alpha Jet and F-16.

When the data were plotted the correlation was pleasingly good. On technical man-hours per pound of empty weight most of the points lay on a curve, with a few points well below and a few well above. Closer inspection showed the points lying well below the curve to be for the aircraft which, for their time, were less-complex, such as the Jet Provost and Hawk. Those above were for designs which were ahead of their contemporaries, such as the Fairey delta FD.2, which established a world speed record and could have become a world leading fighter ahead of the Mirage family had it been put into production, the Bristol 188 all-steel experimental supersonic aircraft, and the ill-fated TSR.2. It was therefore possible to draw three curves as illustrated and, assuming that the parameter shown is representative of total launch cost, it can be seen that for a 'typical for its time' military service aircraft the factor, even when corrected for the effects of inflation, has increased by 15 times. It must be remembered that this is the cost per pound of empty weight, which has itself increased by between four and six times. An example of the effects of the increase in complexity is the increase in the ratio of technical staff to the draughtsmen and loftsmen who actually produce the data for the shop-floor; this ratio has much more than doubled.

The increase in production cost per pound of empty weight has grown at an even greater rate than the launch cost, the factor here being 20 rather than 15. On the other hand, the man-hours per pound of weight to manufacture the air-



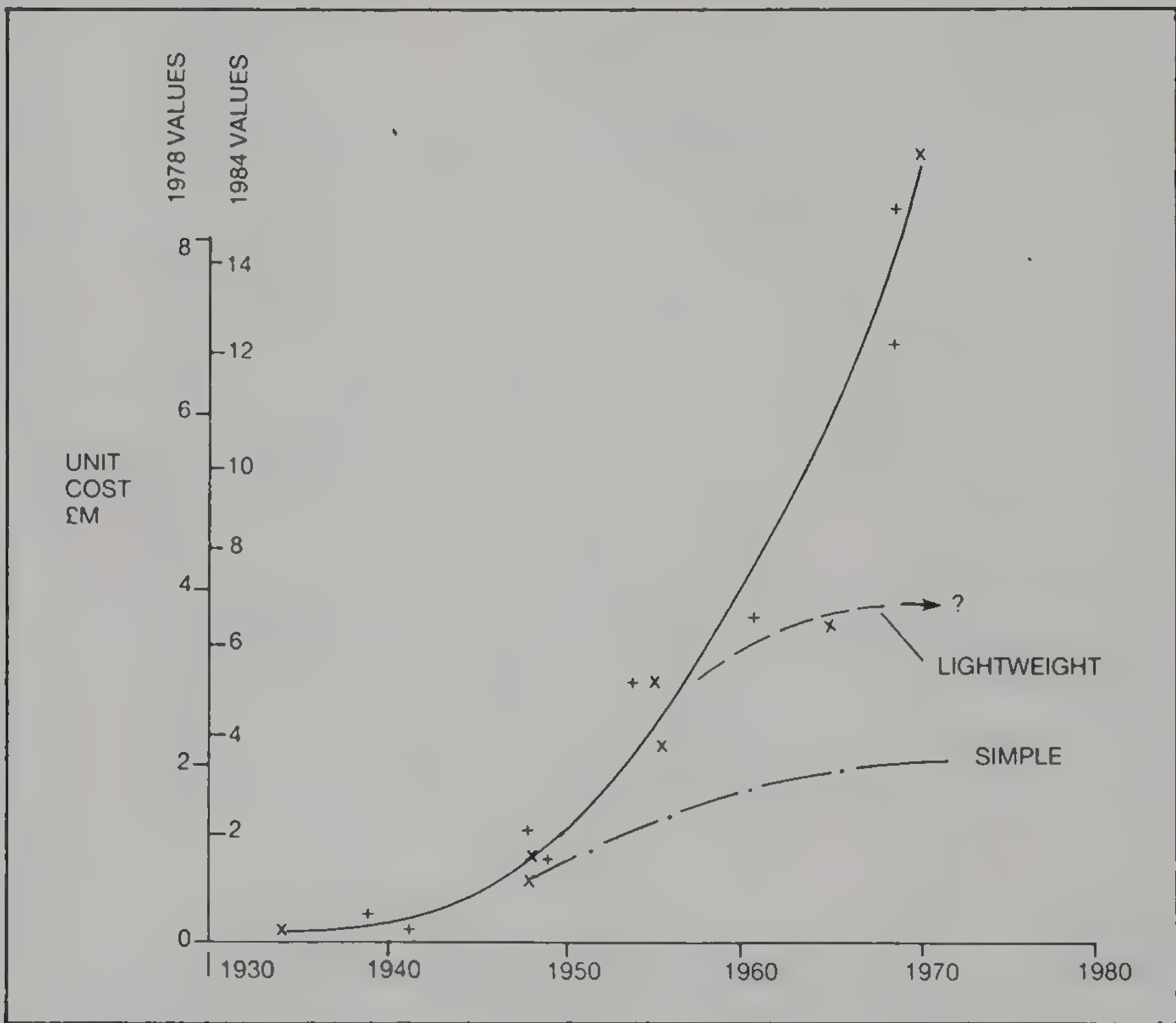
Technical effort to first flight.

frame and assemble the whole aircraft is only about 2.5 times what it was in the 1940s. Machining rather than hand-making many components must be one factor, but the remainder and larger part must be due to the high-value equipment, both mechanical and electrical/electronic, now fitted.

Another factor which must affect cost is the time taken from the start of the programme to both first flight and production deliveries. Over the period reviewed, on average, British programmes have increased from 25 to 45 months to first flight and from 50 to 90 months to first production deliveries. American

programmes, with more sophisticated management techniques and more drive, have over the past 20 years shown a downward trend, to be only about half the British figures. There are fortunately signs that some European programmes are becoming much more competitive, but almost all the reasons for the incredibly long timescales are political.

It is certainly vital to reduce the time taken, Labour costs are largely a function of time and, in addition, there is the effect of inflation. Delay also gives competitors the opportunity to saturate the market.



Typical unit cost growth.

International collaboration

As a means of increasing the return on investment, international collaboration has already been shown to be advantageous. The benefits in a multi-national organization such as NATO, of having common equipment in a number, if not all, of the nations involved is not to be underestimated. Collaboration also puts a heavy damper on the tendency of individual nations to cancel a project when it is partially completed. There is also the hard fact that a modern major project may be beyond the financial capability of a single nation, and partners have to be found to make it achievable.

In principle, therefore, apart from being a platform for politicians, international collaboration has many merits. It is not, however, a bed of roses. In the first instance, the definition of an internationally agreed project is far from easy. It may well take from three to five years, which is equivalent to the time taken from start to first flight.

The procedure by which such agreement is to be reached is by no means clear. Is the initiative to come from industry or from an air-staff base? Whichever way round is the initiative, both elements have to reach agreement before the project can proceed, and the discussions may be complex and tedious, Inevitably, international compromises have to be made before a final specification can be agreed. Work-sharing between the different national industries is itself becoming an increasing problem. In the case of Jaguar and Tornado, a good basis for reaching agreement comprised breaking the work down into components, with final assembly in each participating country, the total value of the work placed in each country being related to the size of its purchase. With the leap forward in technology now occurring in structural materials and processes, active controls and avionics development, every country wants a stake in each activity, and this significantly compounds the problem or work-sharing.

The cost reduction from international collaboration is by no means as great as simplistic theory would predict. First, project launch can — indeed, is likely to — be delayed by up to several years. Secondly, experience to date suggests that the programme will take one to two years longer than if it were undertaken nationally. Thirdly, programme costs will be increased by at least 10 per cent.

Nevertheless, international collaboration on at least some projects is here to stay. There is enough experience now available, particularly from Jaguar and Tornado projects, to optimize the organization and procedures on both industrial and governmental sides.

Project conception

It was at one stage the norm for each new project to emanate from industry in direct response to an officially issued specification. Very often, it was literally a direct response to what had been written, rather than a well-balanced design with good all-round sales prospects. Up to the late 1940s or early 1950s new requirements came out at a high frequency, so that a few mistakes could be afforded by both the nation and the industry as a whole, although possibly not by the company concerned. There was in those days considerable movement of staff to wherever the work happened to be.

A wholesale succession of major cancellations in the 1950s and 1960s, for a combination of political, financial and technical reasons, or in some cases where the specification was just plain wrong, made industry increasingly suspicious of the traditional methods of obtaining business. Although in the limit, the cancellation charges can be said to have been affordable, and the companies concerned were paid for the work which they had done, the abortive deployment of their best brains over a considerable period severely prejudiced the generation of new business in the timescale in which it was needed, besides being outrageously wasteful.

With the ever-increasing gap between new projects, the role of the Future Project offices was changing from being primarily one of responding to issued requirements to being one of continuous self-generated study. The technique of operational analysis began in some operating headquarters during World War 2, and was increasingly taken up within government establishments. This was not always for the better, for, without a good working knowledge of the hardware involved, things could go sadly astray. There would be, and still is, a danger of

forgetting the assumptions made in the first instance, and giving the conclusions reached a greater spectrum of validity than was justified.

The combination of the availability of facilities within industry for large-scale computing, and later simulation, and the adverse rate of project generation which had developed, led to industry embarking on extensive operational study investigations and integrating them with their Future Project design studies. Starting effectively in the late 1960s, these activities grew steadily to reach today's substantial level.

This has lead to a new relationship between industry and the operator/customer. We have a far better understanding of each other's problems, with industry able to make a significant contribution into an operational need in addition to putting forward a practical solution. In these days this must encompass the aircraft/weapon combination, not just the aircraft.

Whilst not all the members of the customer establishments welcomed this invasion of their territory, the comments made in 1980 of some retired senior Royal Air Force officers seem to be worth recording:

(i) 'Way back in the early 1950s I very boldly suggested to a conference of aircraft chief designers and senior officers in the Royal Air Force that I did not believe that it was necessarily true that the Royal Air Force alone possessed the people who should determine operational requirements. I said that there was a continuity in industry which was lacking in the Royal Air Force, with changes in appointment every two of three years, and that industry should become more involved.'

(ii) 'There is the need for the aircraft industry to take more initiative in shaping the forward operational thinking of the Royal Air Force. My Ministry of Defence experience leads me to believe that perhaps industry itself has been too diffident in the past in making its ideas known . . . Having seen AST.396 torn up and replaced by something entirely different (the eventual AST.403), I was exposed to a first-hand account of how air force operational thinking can be changed overnight. I personally think that AST.396 was ill-conceived in the first instance, but I wonder if anyone in the aircraft industry attempted to influence the original proposals, or whether they simply responded to the whims of the Air Staff at the time.'

(iii) 'The interaction between the Operational Requirements branches, the specialists, the Procurement Executive and the research establishments causes long delays . . . It would require considerable rethinking on the part of the Air Staff to effect changes, not least of which would be a revision of interface between the Air Staff and the Procurement Executive, and for a much smaller body to be given the responsibility for the procurement of new weapons systems.'

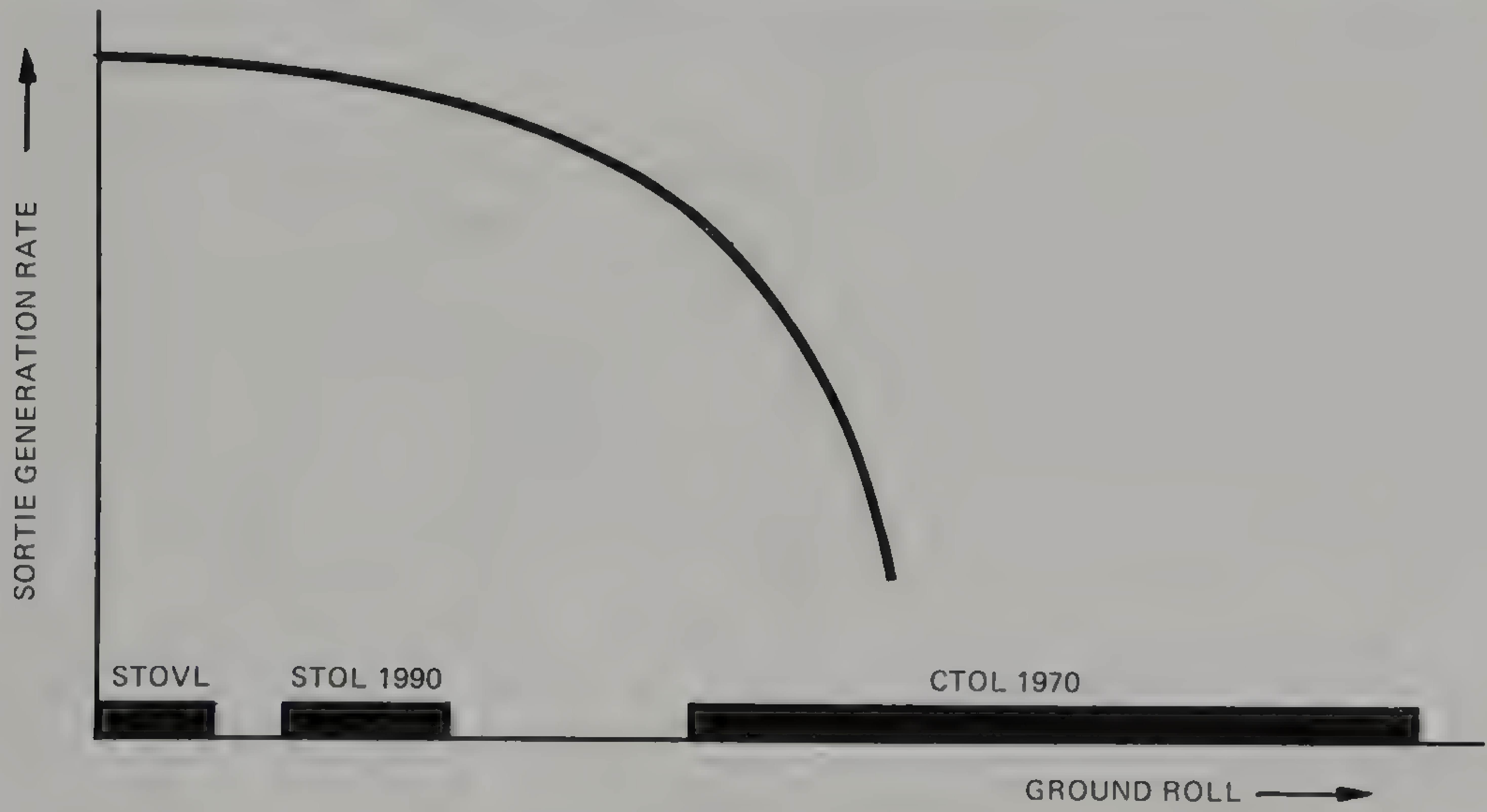
The last remark was based on the officer's experience of American and French procedures. I do not myself know of any industry influence on the formulation of AST.396, but certainly some of us, in attempting to respond to it, felt that it was wrong. Based on our own operational studies, we pressed for something very much like the subsequent AST.403.

Operational studies within British Aerospace, with also a degree of collaboration with work at MBB in Germany, in conjunction with design studies in the Future Project office, led directly to the much-publicized industrial initiative

with the P.110 high-performance fighter. The establishment took a lot of convincing, and then ruled that any such project must be international. Negotiations were becoming protracted when, thankfully, the United Kingdom Government augmented funding from industry itself, to enable a single demonstrator aircraft to be built. This EAP (Experimental Aircraft Programme) serves as a bridging operation which has led to the multinational Eurofighter proposal, which despite repeated delays seems likely to mature. It must be mentioned that this is 8 to 10 years after a very similar trinational proposal was put forward.

At least it can be seen that industry-based project studies encompassing operational analysis techniques are now having some effect. For the benefit of readers not familiar with the technique the following are typical examples of the work done.

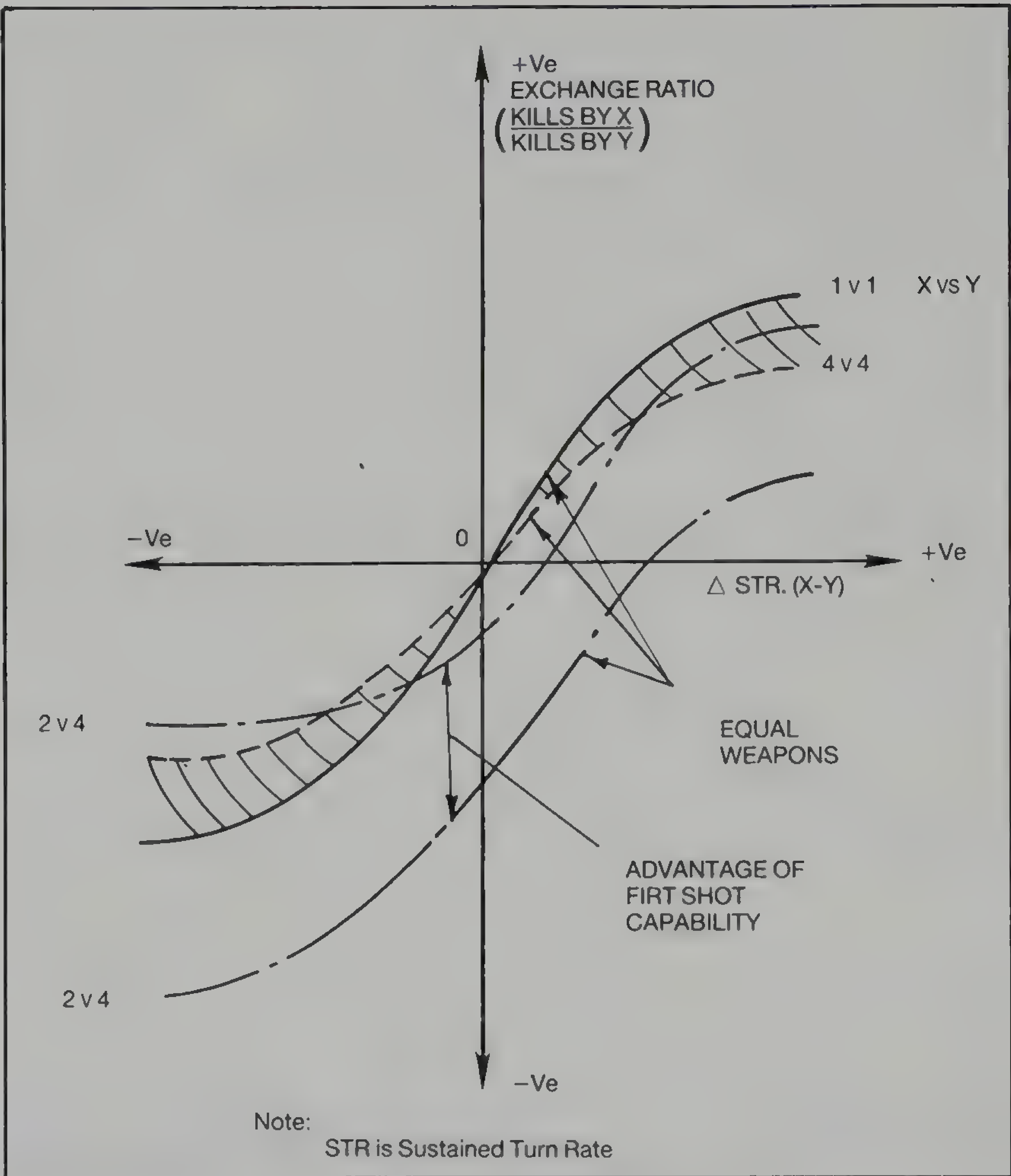
In the late 1970s a CAS (close air support) aircraft with supersonic capability was under study. The Royal Air Force was showing enthusiasm for it to have a



The effect of counter air attacks.

STOVL capability, in view of likely damage to airfields; in other words, it was a supersonic Harrier. It was possible to estimate the strength and frequency of raids on the airfields and to define the probable damage and repair time. With the knowledge that takeoff and landing performance far superior to that of the types then in service could be built into the next-generation aircraft, calculations were made of the number of sorties which would be possible in the day for a range of takeoff and landing capabilities, with the result as illustrated. The conclusion reached by those undertaking the study was that, as expected, while the current aircraft would be very severely restricted, the short takeoff and landing capability which could be provided with the next-generation aircraft was good enough for the same number of sorties to be achievable each day as with the technically more difficult STOVL aircraft.

The limitations of, and deductions from, this analysis need to be recognized. What if the raid frequency is greater than that assumed, such that repairs cannot be effected as assumed? Whilst the overall number of sorties over the day achievable by both types of aircraft were equal, there were periods when the



Melée combat exchange ratios.

STOL aircraft could not operate, but when it was possible that the STOVL aircraft might well be able to do so. If such a period coincided with a critical point of a battle, the consequences of not having the STOVL capability could be catastrophic.

A separate study was made of the possibility of operating the STOL aircraft from major roads in the battle area. A survey of likely areas showed an adequate number of strips to be available, using one carriageway of dual-carriageway roads. However, road signs, lamp posts and even trees required removing, and this could take up to two days and in some cases even longer. The questions which inevitably arise are, 'Will there be sufficient notice of hostilities to allow such work to be done?' and, 'Will the capacity of the one remaining carriageway be sufficient to cope with the road traffic at the time?'

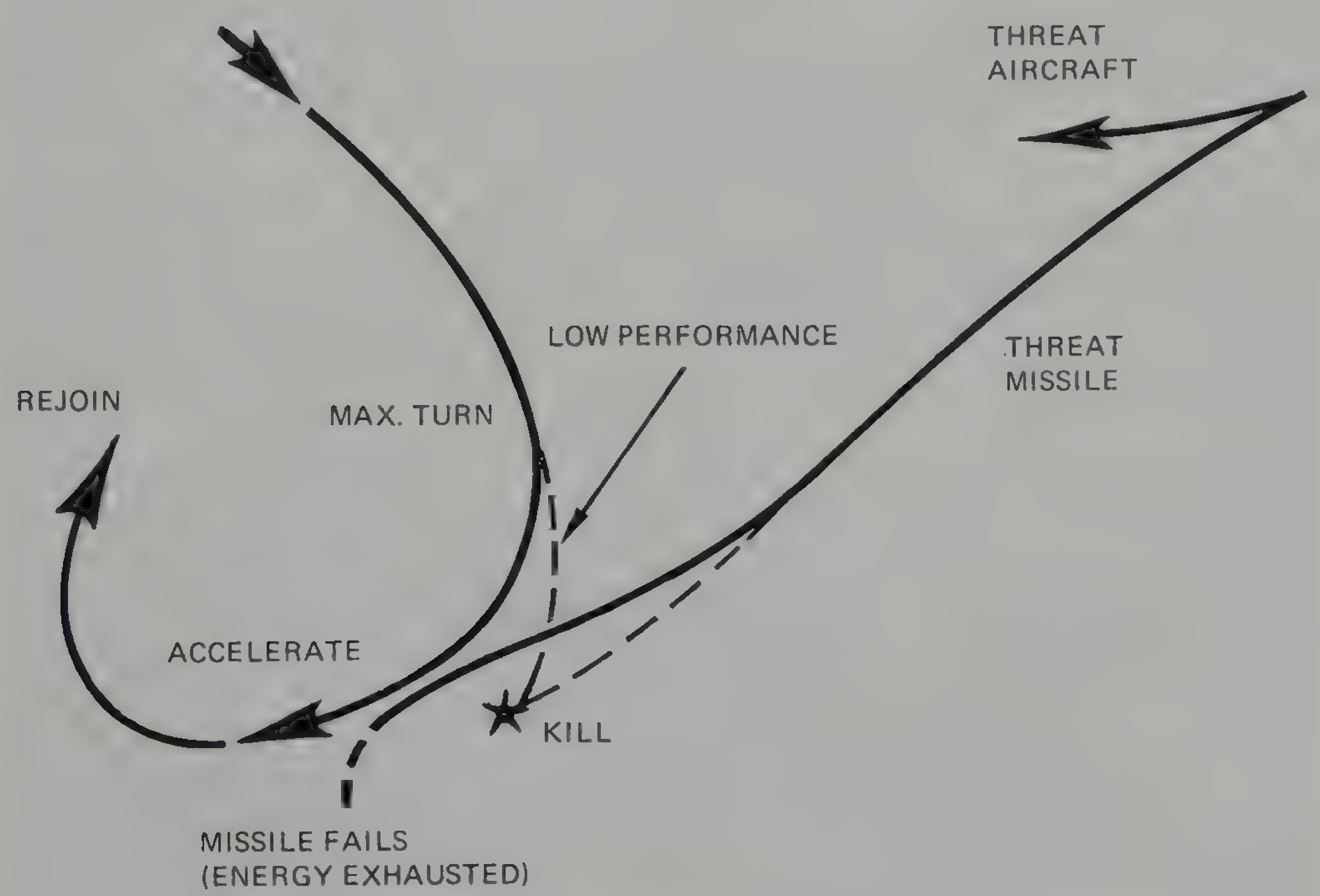
It can be seen that both the protagonists and antagonists of STOVL can use the results of these studies to support their case.

Studies of close air combat, including pilot-controlled simulations, were undertaken to assess the level of performance required for success in the classical dogfight situation. These combats will always take place at subsonic

speeds, and the tendency is for the speed to progressively decrease during the combat. One aircraft versus one and multiple combats were included. The results showed quite clearly that there was a value of thrust:weight ratio which had to be exceeded, after which success was highly dependent upon having a superior rate of turn. Numerical values were established, whilst also assessed was the effect of improvements in the characteristics of the short-range air-to-air (SRAAM) missiles with which the aircraft were equipped. One interesting factor which came to light was a great improvement in successful kills which could be obtained by a fighter having a thrust-vectoring capability, as was shown by the Harriers in the Falklands conflict — provided, of course, that the aircraft has the performance to position itself into the right area for the conflict to take place.

The more modern development for air-to-air combat is the medium-range air-to-air missile (MRAAM), which can be launched well outside target visual detection range to home onto the target either along the radar beam of the launching aircraft, or by the use of its own sensors, or by a combination of both. Assuming that the fighter pilot is prepared to launch his missiles under such conditions, what effect does varying the aircraft performance have on the operation?

One comparison made was between two aircraft, one of which accelerated to a Mach Number of 1.8 in the time that the other attained 1.1, and which at the same time attained a 40 per cent greater altitude. The greater energy imparted to the missile from the higher speed and greater altitude launching condition provides it with a 30 per cent greater range. Some would say that this is important but, unless identification of the target is more positive than appears to



Evasion of opposing MRAAM

be the case today, missiles launched at maximum range are likely to be a very rare occurrence.

Another aspect investigated concerned the evasion by the target of a missile fired when both opponents were flying at supersonic speed. It can be shown that, provided the fired missile is detected in time, and if the target's supersonic turning performance is high enough, it can evade the missile until the latter runs out of energy and falls out of the sky. By studying pieces of the jig-saw in this way, and relating them to design studies, more effective projects can be formulated and more effective discussions instituted with potential customers.

In a similar manner, air-to-ground attack operations can be studied in detail. Target detection by different sensors, and the associated manoeuvres to complete an attack, can be evaluated. The attack manoeuvre required will vary with different weapons, as will the probability of aircraft loss. Thus, an overall picture of aircraft and weapon effectiveness can be built up for a range of options.

Using the combination of operational analysis techniques, and aircraft and weapon design studies, industry has taken a great leap forward in assessing complete weapons systems, and hence in producing better based proposals. To divorce such work from realistic design studies would be a great mistake, as would be the forgetting of the limitations of the assumptions made in the first instance. If mishandled, such work can be distorted into becoming the calculation of assumptions to validate predetermined conclusions!

Project launch

Some of the aspects of achieving the successful launch of a new project have already been discussed, including the problem of the cost factor, obtaining international collaboration where necessary, and, with the use of operational-analysis techniques, producing a proposal which adequately meets the needs of the maximum number of potential customers. It is highly desirable to have the launch customer at home, which in our case means the Ministry of Defence. This can be quite an obstacle to overcome.

In a lecture to the Royal Aeronautical Society in 1980 I said, 'Somehow we have to break through the interminable "study and discuss" period and to redevelop an atmosphere of confidence. Remember that a lightweight fighter concept was active within British industry in 1970, but it failed to enlist any official support. What might have been our share of the market now taken by the French Mirage F1, the F-5 and the F-16?'

To some extent the 'study and discuss' procedures resulted from the disaffection with both industry and government procedures which arose following the disastrous events of the 1950s and 1960s. In that period, an era of great technological change and hence of uncertainty and risk in programmes, there were some serious cost-overruns which the then-normal practice of 'cost-plus' contracts gave little incentive to contain. In addition, there were numerous cancellations of projects already embarked upon, often due to errors in formulating the original requirement. To attempt to combat such misadventures, in turn Sir Solly Zuckerman, Sir William Cook and the Downie report introduced procedures to give both better forward planning and more effective monitoring and control of projects in hand.

In the first instance, a scenario was written, to be followed by a feasibility

study of possible solutions. Having defined preferred solutions, project definition would proceed and be assessed, prior to the placement of a development contract. Project definition was to be made in two stages known as PD.1 and PD.2, with an assessment after each stage, the second-stage definition being in greater detail than the first. Following the go-ahead for the project, the development work and production activities were to be broken down into milestones against which progress and spend were to be monitored.

This was all laudable and logical and a distinct improvement on what had gone before, but what really matters is how theory is put into practice, and this can go sadly wrong. To illustrate the possible negative aspects, in my 1980 lecture I parodied some of the definitions. Unfortunately each parody had a strong element of truth in it:

Scenario: An attempt to simulate the true operation of the aircraft, or more often a device used to define an optimum solution. The assumptions used are often contentious, and will almost certainly be out of date by the time the project enters service. Valuable for assessing trade-offs, but dangerous to use as the basis for a specification.

Feasibility Study: An exercise to prove that a project is credible and should be pursued. During this time, a potentially collaborative partner actually does it, thereby showing that the feasibility study was soundly based.

Project Definition: The two stages, PD.1 and PD.2 can be said to mean project delayed once and project delayed twice.

Milestone: Sometime very difficult to define and/or identify. In some cases becomes more like a millstone.

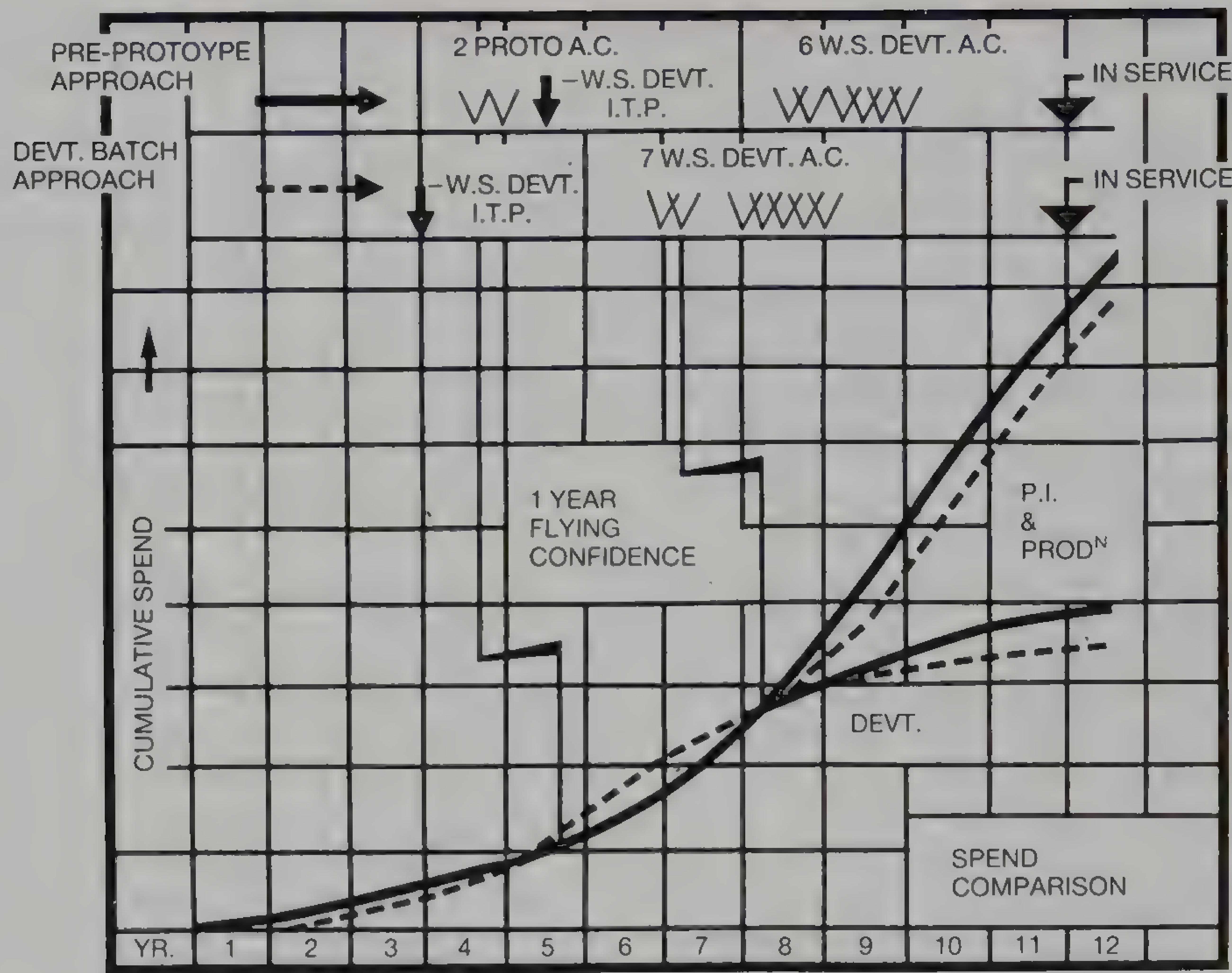
The real warnings of potential dangers in the implementation of basically sound procedures are:

We live in a world of intense competition, military, commercial and technical. Time is therefore of the essence, and all procedures must be implemented expeditiously and not be subject to any bureaucratic delays.

Attempts to formalize and optimize on a purely scientific basis are doomed to failure. Rarely has an aircraft built rigidly to a specification proved to be successful in service, and then more often than not it was successful in a different role from that originally envisaged. The entrepreneurial instincts of the designer must be added to the results of operational analysis to produce the right degree of flexibility into a well-balanced design. The remarks of the retired Royal Air Force Officers quoted earlier underline this.

With the time between major projects now not less than ten years it is inevitable that each should contain substantial technological leaps-forward, and hence incur relatively high risk. For a full development programme the financial commitment could well be a £3,500 million launch cost, with the purchase on a national basis of £4,000 million for the aircraft alone, without the support and other life-cycle costs. The establishment tends to regard any proposal put to them in this light, and one can readily understand their hesitancy.

To attempt to get more dynamism into the situation, in 1980 we were proposing what we called a pre-prototype approach. Two aircraft, not fully equipped for operations, could be designed, built and flown for a year to give meaningful proof of concept before any full programme was undertaken. Such a programme



Pre-prototype and development batch approaches.

would cost, say, £300 million, which is a vastly different proposition from the £7,500 million plus for a full programme.

The programme and associated spend for a pre-prototype approach, followed by the development and production of a service aircraft, can be compared with the traditional approach. The average annual spend of a pre-prototype programme over a five-year period is £60 million. When compared with an annual turnover of the British aerospace industry of £4,000 million, such a programme should be affordable every few years. Having said that, there are certain provisos. The turnover figure is for the whole aerospace industry, not all of whom would be involved in the exercise, so the turnover-to-spend ratio of those who were involved would be somewhat lower. Then means have to be found to integrate all of the parties to organize both the work and the finance, the latter placing the equipment suppliers in a quandary, as there is no guarantee that they would have the same participation in any follow-up main programme which hopefully would result. Naturally, such a main programme is an important aim of the industrial initiative, and one would therefore be looking for at least some measure of government support for the venture, which would best be shown by a measure of financial support. Thus the proposal would be for a joint industrial and government programme, which would at least advance the state of the art even if it did not lead to a full project.

Fortunately, in the early 1980s a large enough group of industrialists joined together to study and promote new business, and this led in time to the Experimental Aircraft Programme (EAP) going ahead, financed jointly by industry and government to get a new advanced aircraft into the air. During the programme some international activities were included, with contributions coming from Italy and to a lesser extent Germany. For political reasons the EAP

was designated as a mere technology demonstator and not as a pre-prototype, although in configuration and airframe systems it very closely resembles what we think the next-generation fighter should be like.

The argument in 1980 for the pre-prototype approach, apart from accelerating tangible progress at an affordable cost, also postulated that it should be an effective method of generating an international project, and far more effective than paper exercises and discussions. This the EAP has turned out to be. The EAP grew directly out of the P.110 fighter industrial initiative, and in its turn has led to the establishing of the Eurofighter (EFA) project with its international organization. This originally consisted of the United Kingdom, Germany and Italy, but Spain has joined, and more nations may do so.

Prior to the start of the P.110 exercise two very significant events had occurred within the British industry. In 1978, with the emergence of British Aerospace as an organized entity, the Managing Director Military Aircraft, Alec Atkin, and the Managing Director of the Dynamics Group, George Jefferson, called together a large meeting of engineers from both groups to make each other aware of their current activities and future thinking. It was a success, and it was decided that meaningful collaboration between the two groups should be set up on a permanent basis with an executive from each group to be jointly responsible for this activity. For the Dynamics Group the task was allocated to Laurie Evans (later Air Commodore Gerry Watson) and for the Aircraft Group to myself. Over the following years we held periodic meetings with representatives from every site involved in the activities, with, in addition, smaller working parties studying specific topics. A very constructive activity this turned out to be, with cross fertilization of ideas and a more integrated approach to the aircraft/weapon combination.

It was in 1980 that, having struggled with AST.403 and proposals for the European Combat Aircraft, the enormity of the task of defining and generating the avionics systems and integrating them with the airframe became fully appreciated. It was felt that any proposals to the government for a future project should be put forward by an integrated body capable of undertaking the task as a whole.

A meeting of managing directors representing aircraft and avionics companies with a total systems capability decided to co-operate. Periodic meetings were held, eventually including airframe equipment and engine suppliers, in addition to the avionics companies. A steering group of senior engineers was activated, both to organize working groups and to keep the managing directors informed. I acted as chairman of the steering group and for a time as secretary of the managing directors' meetings, and so was heavily involved in the evolution which finally produced the industrial framework to support the P.110 and later the EAP and EFA. Thus from the post-AST.403 wreckage of 1980, we have created improved procedures for maintaining progress in advancing technology and/or of launching a new major project.

Choosing from advancing technology

With today's rate of advance in many technologies, the selection for his own application may place the designer in a dilemma, especially with a possible period of eight to ten years before entry into service followed by 20 to 30 years

in service for the eventual aircraft. Many of the options available may affect choice of configuration, and also require radical changes in shop-floor techniques and equipment. The actual rate of technological progress is such that it would be unwise here to discuss particular areas in detail, but a general overview would seem helpful.

Structure

Use of carbon-fibre composites can give a 10 to 20 per cent weight saving and up to 10 per cent reduction in cost. At first sight this must be very attractive, but totally new shop-floor equipment and techniques such as tape-laying, autoclaves for forming and curing, together with clean room facilities, all have to be provided and understood. Once the manufacturing techniques have been mastered, the selection of the appropriate parts of the aircraft in which to make use of this new material has to be considered very carefully. The evidence is that, whilst the composite materials are very strong in terms of static load, they are prone to shatter under impact loads. Thus, for instance, they are not suitable for wing leading-edge structures, but are well suited for wing torsion box spars, skins and movables such as trailing-edge flaps and spoilers.

Aeroelastic tailoring for varying strength and stiffness over the wing in a manner not practicable with metal can be put to good use. This in itself not only gives better structural efficiency but also allows some hitherto impracticable configurations such as swept-forward wings to be considered.

Apart from foreign objects striking the structure, a further type of impact load which can militate against the use of composites is hydraulic shock following an explosion in a full or partially full fuel tank. On a combat aircraft it may therefore be advisable to limit wing fuel tank capacity to that which would be used prior to combat, placing the remainder in either a metal fuselage tank or external tanks.

It follows from this that, whilst cockpit areas of the fuselage may well benefit from carbon-fibre composite construction, centre fuselages which normally contain large-capacity fuel tanks in addition to equipment are best made of metal. So too would be the rear fuselage if, as is often the case, it is exposed to the heat of the engine exhaust.

Advances in aluminium alloys, such as those which are now lithium-based, make some decisions as to whether to use composite materials or not rather easier. Weight savings of up to 15 per cent are possible, and they are therefore competitive with carbon-fibre composites, but with a cost penalty rather than cost gain. Alleged to be interchangeable with conventional alloys in terms of manufacturing processes and techniques, some question marks remain until more experience has been obtained, and more development work taken place.

Another new technique, particularly applicable to complex-shaped components, is that of SPF/DB (superplastic forming and diffusion bonding), which can be applied to either titanium or certain aluminium alloys. In this, the metal is heated up to a very high temperature in a mould both to join separate pieces of metal and to form the whole into the appropriate shape. Weight savings of between 10 and 30 per cent are possible, with cost savings up to 40 per cent.

With modern CAD (computer-aided design) techniques giving more effective stressing of components, added to the availability of these new materials and processes, cost and weight savings of a significant order are possible. On the

other hand to get the combination right with the present state of knowledge is an onerous task for the designer, such that some level of risk cannot be avoided.

Avionics

The rapid and widespread advances in electronics, which show no sign of abating, are having a major effect on the design of the aircraft and on its capability. However, with a ten-year gestation period, an in-service life of over 20 years, and with a new generation of electronics arising every five years or so, the designer and the operator are faced with formidable problems. The designer has to choose upon which standard of avionics to base his design, and at the same time minimize the subsequent problem of incorporating an updated system. The operator has to decide when and if an updating is economic, and this includes the effects of taking the aircraft out of service, possibly for six months or more, whilst the updating takes place. For the civil operator this is a loss of revenue. For the military operator, with the limited purchases of his aircraft so current, he must decide whether his commitments will allow him to take his aircraft out of service for this purpose, to which must be added the problems of supporting a mixed fleet over a prolonged period.

The advances which have occurred have provided a revolution in aircraft systems management, and also in cockpit workload and combat capability. The advent of the electronic cockpit, with its multifunction cathode-ray-tube displays, allied to extensive digital computation of the data available, has permitted an important reduction in the flight crew of modern airliners. Apart from the improved display presentation, the information required at any given time can be selected, rather than gleaned from a mass of dials which are displayed all the time. With the digital processing of systems data, failures and the necessary corrective action can be flashed up as they occur. For the combat pilot the gains are even more spectacular. Vastly improved navigation and combat information can be displayed as required, to which can be added the displays on a holographic HUD (head-up display) with additional information electronically transmitted onto an HMS (helmet-mounted sight). Monitoring and recording of systems information during flight can also greatly assist the ground crews, and improve turnround times and reduce costs.

The enlistment of avionics to integate flight-control functions, together with advances in aerodynamics, has greatly improved both cruise efficiency and combat manoeuvrability. Leading- and trailing-edge flaps can be programmed to vary camber to an optimum position to meet the demand. By programming to give the system an effective intelligence, 'carefree manoeuvring' facilities can be incorporated such that the pilot cannot exceed safe limitations no matter what he does.

Finally, with digital processing of the aerodynamic characteristics of the aircraft and of the input from the pilot's controls, controlled flight of an aerodynamically unstable aircraft has become possible. This can not only improve the aerodynamic efficiency of conventional configurations, but has also led to the use of less-conventional configurations such as the delta plus a foreplane, or canard delta.

In the earlier generation of avionics, the so called 'black boxes' were usually specially made for a specific function, and were often applicable to one type of aircraft only. The avionics manufacturer generally regarded himself as providing

this particular function, leaving the aircraft manufacturer responsible for integrating the function into the aircraft as a whole. To alter the function inevitably meant a change of black box. With the new technology, digital computers and microprocessors fulfil a huge variety of functions with appropriate programming, the latter being known as software. Alterations to the function can now be achieved by a change to the software, with far less pain for the operator.

This change of technology does, however, present some problems for industry. No longer does the avionics equipment manufacturer supply a special-to-purpose piece of equipment. With the modern systems, comprising digital data-buses and processors linked together on a multi-function basis, the emphasis is placed on the aircraft manufacturer for allocating functions and integrating the various sub-systems. The avionics companies, to some extent, become suppliers of more or less standard bits. Evolution cannot continue without the avionics companies ploughing in risk money, and they do not view this encroachment into their traditional territory with any enthusiasm. As mentioned earlier, progress with new aircraft projects is highly dependent upon aircraft and equipment manufacturers integrating their facilities, and jointly financing radically new ventures. Thus some sort of social, as well as technological, revolution has to take place in the industry as whole if a progressive and prosperous future is to be ensured.

With the vast potential of the new avionics systems, it is not surprising that they have created problems of their own. By far the greatest of these is in the writing of the necessary software. The man-hours required for this task has increased many times over during the past ten years. Both the provision of manpower, and the establishment of management systems, to allow software changes to be incorporated and recorded without disrupting the overall systems, have been unceasing worries. Experience has shown that the programmes are best written by the design engineers themselves, rather than by software specialists. Frequently when this practice was followed, such is the national demand for software writers, that no sooner were the design engineers competent in the necessary software writing than they were enticed away by a software house. This has repeatedly left the aircraft manufacturer not only short of software writing capacity but also of valued design engineers. The output of our educational system is a tiny fraction of the demand, in either discipline.

In April 1984 the Royal Aeronautical Society held a two-day symposium on avionics developments at which the various specialists outlined their activites and successes. At the close, and before joining the panel of a round-table discussion, two of us, a helicopter designer (Mr Austin of Westland) and an aircraft designer (myself) were invited to put forward our points of view on the advancements which had been offered.

With only a few minutes to deal with such a complex subject I decided to put up two series of caption slides, one on the possible benefits on offer and the other on the problems which could arise in implementing them. My talk followed very much on the lines of the foregoing, the captions being:

Benefits: reduced cockpit workload, increased aircraft performance, housekeeping in-flight and turnround, and ease of change.

Problems: Technology pick-off timing, Integration/redundancy/testability, change of industrial emphasis, and software writing and management.

At the end of this presentation I said 'And this is what we are doing to try to resolve the problems'. You could hear the audience take a deep breath and pay rapt attention, only to explode into gales of laughter when I put up a slide of me gazing into a crystal ball.

Aerodynamics

Advances in computational techniques for wing design and in the electronic integration of the various aerodynamic devices have led to greatly improved performance. Lift available for takeoff and landing has been increased by some 50 per cent, cruise lift/drag ratio by up to 60 per cent, together with greatly enhanced manoeuvrability at higher Mach Numbers. The advances in wing design, for instance, have improved combat turning performance by 17 per cent, but, when coupled with the now practical aerodynamically unstable aircraft, the improvement is increased to 35 per cent.

The use of a delta planform has long been advocated for supersonic performance, but in the traditional tailless configuration, with trailing-edge elevons, and with natural aerodynamic stability, it found little favour for application to a combat aircraft. Subsonic induced drag was high, placing the configuration at a disadvantage in the highly important subsonic combat manoeuvres. Adding a foreplane improves control and aerodynamic efficiency which, together with artificial stability, gives the canard delta equal subsonic and superior supersonic turning performance, to bring it into serious reckoning.

There is a limit to the degree of natural instability that can be managed by an electronically signalled active control system. Carriage of underwing stores, which is an almost universal practice, produces a destabilizing effect, and this must be allowed for in setting the degree of instability in the basic airframe. The effect is more severe on the canard delta than on a conventional tailed design. The size of the store in relation to that of the aircraft is an important parameter; the smaller the aircraft in relation to the stores to be carried, the less is the case for the canard delta. As a pure fighter it must be the choice, but for a multirole aircraft the overall case is far from clear.

The aerodynamics of the FSW (forward-swept wing) have been understood for the past 40 years or so, but it has taken the advent of carbon-fibre composite construction to give the aeroelastic tailoring essential to make the concept even worth considering for a high-speed manoeuvrable aircraft. Subsonically, up to a Mach Number of 0.9 or so, the swept-forward wing is more efficient than the swept-back. In particular, it has a higher lift/drag ratio, and enjoys freedom from tip-stalling and its associated pitch-up problems. Supersonically, size for size the FSW has a higher drag, but if the superior subsonic characteristics allow a smaller aircraft to be made, the reduced size may give adequate compensation. There may be layout factors which make an FSW configuration preferable, or a particular subsonic characteristic may point in this direction. However, overall it would be a venture into the virtually unknown, and would seem to be an unlikely step until experience has been gained on one or two experimental aircraft.

Again, in the aerodynamic context, the designer must make up his mind which way to go, although with the certainty that the modern product will be decidedly superior to its predecessors.

Propulsion

Apart from the introduction of integrated electronic control systems, the major developments which have occurred in propulsion technology over the past 20 years have been in improved compressor efficiency and increased temperatures at the hot end of the engine, together with radical improvements to reheat systems.

Compressor developments have led to much higher overall pressure ratios and/or a reduction in the number of stages, thus helping the designer by giving him a shorter engine. Materials technology has permitted a leap forward in maximum tolerated temperatures in the turbine, thereby increasing thrust for a given size of engine. Development of reheat systems has led to a vastly reduced length of the reheat pipe, with the associated advantages to its installation and weight.

So finely tuned are some of the most modern engines that variable-cycle features are under development to enable the engine to function more efficiently over the full operating range. The precise choices are various and complex, but introduction of such features into next-generation engines, and even into later variants of current engines, seems to be inevitable.

The order of improvements which have been effected include a 20 per cent increase in pressure ratio, a 15 per cent increase in turbine temperature, and a 7 per cent increase in reheat temperature. The combined advantages to the aircraft designer include a 25 per cent increase in dry thrust/weight ratio and a 50-60 per cent increase in thrust/weight ratio with reheat, in addition to which there is a 30-40 per cent reduction in the overall length of an installation with the same reheated thrust.

These developments, which should progress even further, are of enormous importance in helping to make combat aircraft smaller and of higher performance. Not everyone will be satisfied with this, unless a VL (vertical landing) capability is also included.

The problems associated with a VL capability arising from such engine developments are discussed in a later section, where proposals for complex arrangements to minimize the adverse effects are outlined. One major problem is hot-gas reingestion; when the aircraft is hovering close to the ground the hot gases circulate upwards and are to some extent sucked into the engine intake. At best, this results in a loss of thrust; more seriously it can cause engine surge, with possible loss of the aircraft. Ground erosion due to exhaust temperature and/or pressure and the safety of ground crew and nearby equipment have also to be considered.

Project Studies of the 1970s and 1980s

AST.396

Design studies against the Royal Air Force requirement of Air Staff Target 396 occupied much of the first half of the 1970s. The concept was for an aircraft to operate in the battlefield zone, particularly in the anti-armour role, under all weather conditions, day and night. This required a sizeable pack of advanced avionics and, to make the most of it, sophisticated weapons. Preferably STOVL or, failing this, STOL characteristics were considered to be essential for oper-

ation in the battlefield environment. Minor consideration was given to an air-to-air role, but the primary operational requirements as stated prejudiced such a capability.

From Warton came a range of Jaguar derivatives, including new engines and/or wings, and STOVL variants using either the Pegasus type of engine or a combination of lift and lift-cruise engines. Variants of the Tornado were put forward as possible solutions, as were blended body, delta and variable-sweep aircraft.

Kingston initially offered the HS.1185, a supersonic STOVL design whose origin owed something to the ill-fated P.1154. This was superseded by the option of two subsonic STOVL designs, the Harrier B and the HS.1184, the latter having a larger wing and the proposed higher-powered Pegasus 15 engine. As a lower-capability option a variant of the Hawk, the HS.1182-74, was offered. Brough continued to pursue their line of a cheaper 'downmarket' aircraft, with a variant of the P.153 designated the HS.1190. Also pursuing the arguments being put forward by Dr J. E. Henderson, then Chief Scientist of the Royal Air Force, for larger numbers of smaller and simpler aircraft, the previously described P.154 design was prepared. In addition, a variant of the Buccaneer, the HS.1197, was offered to operate in conjunction with the HS.1182-74 or P.154 class of aircraft to cover the more extreme conditions.

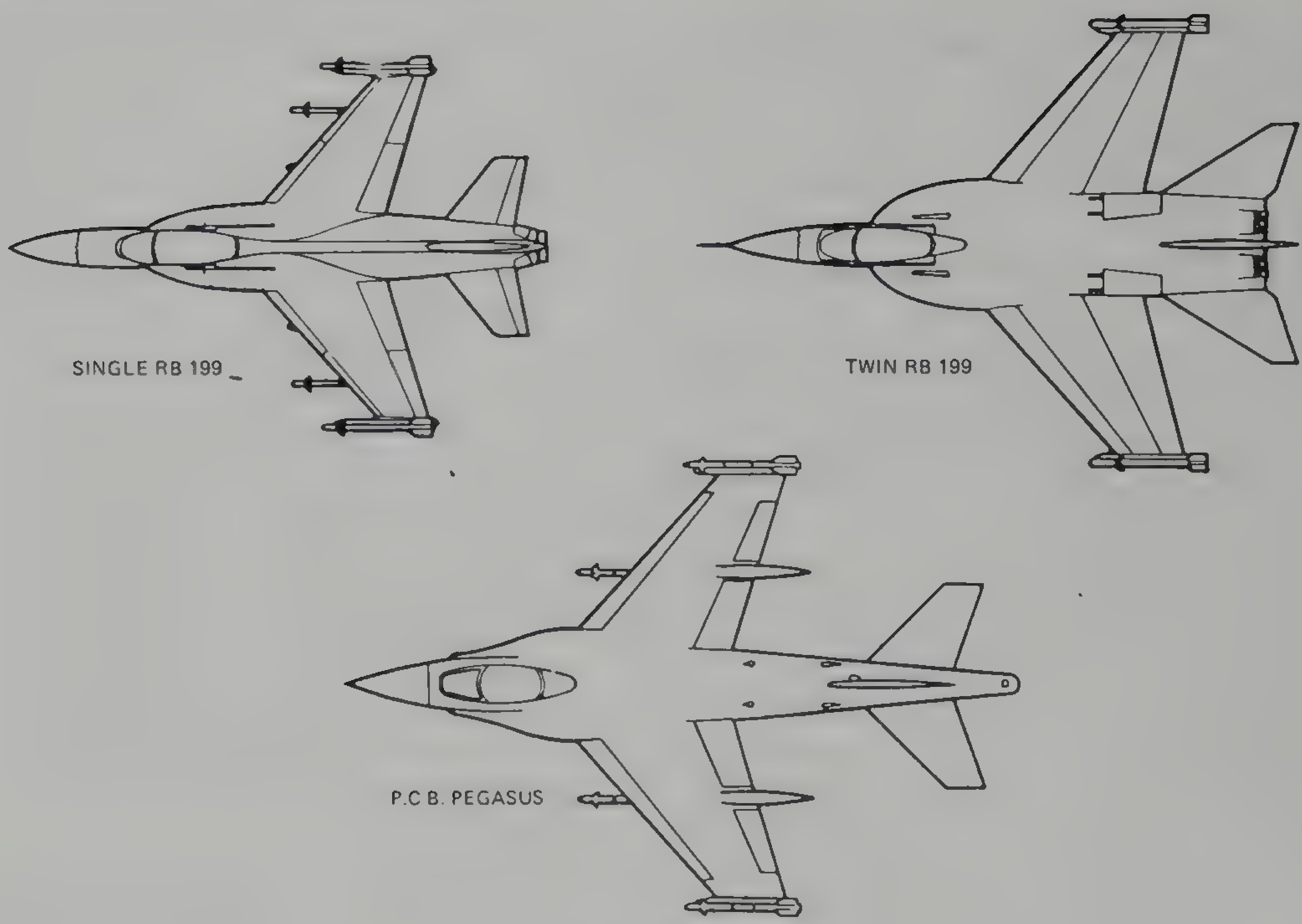
There was a good deal of alarm in the industry that the requirement was too restricted in the scope of the roles specified, and that it was too ambitious in some of the technological solutions needed to fulfil the envisaged operations. In fact, many of us thought that, if a positive project go-ahead emerged based on AST.396, then yet another abortive and financially disastrous exercise would result.

Equipment weights of 5,500-6,000 lb, of which 2,500-3,000 lb was avionics, appeared to be necessary; even this required some significant advances in technology for it to be achieved. Questions arose on the possible use of remotely piloted vehicles to accomplish some of the missions at lower cost, and extensive studies of such vehicles were made at Brough and Warton. A reduction in the scale of the avionics fit to give an equipment weight of 2,000-3,000 lb, of which 500-1,000 lb was avionics, was considered by some to be a more practicable but less-capable solution.

AST.403

It was with considerable relief that we learned of the withdrawal of AST.396, with the subsequent issue of AST.403 which placed the primary emphasis on the air-to-air role. A meaningful air-to-ground capability was still required, but one which was less demanding than that which had been called for in AST.396. Very importantly, an aircraft of much more international interest appeared likely to result from this revised requirement.

This took us into the second half of the 1970s, and a new round of studies was begun. Consideration of the lightweight fighter for this application continued. From Brough came another P.153 variant, the HS.1204, and from Warton the P.95 of similar concept, and the P.97 which was a re-engined and revamped Jaguar. Throughout this period, and indeed up to date, Kingston have persevered with the vectored-thrust Pegasus with PCB (plenum-chamber burning), as a result of which the HS.1205 was included in the AST.403 submissions.



Typical designs (plan views).

Along with these, various more or less conventional twin-RB.199 fix-winged designs were considered, including the Warton P.96 and the Brough P.158/HS.1207. Although various other configurations such as delta wings were studied, three alternative concepts, whose plan views are illustrated, stood out for further consideration.

The single RB.199 design was eminently suited to anyone seeking the light-weight fighter/bomber concept. This did not include the Royal Air Force, who described it as having half the effectiveness of the twin-engined aircraft at two-thirds of the cost. Against this, one can argue that the shortfall of performance would have significance only on a small minority of occasions, and even then it might be offset by the greater numbers which could be available from a fixed budget. In addition, a third-world export market should be open for such an aircraft. Traditionally the Air Staff have based their consideration on their own requirement only, export markets being someone else's sphere. If a system were to operate where they drew some financial benefit from export, either potential or achieved, this situation might (and obviously should) change. However, things being as they are, the small-aircraft concept failed to enlist any support.

The supersonic STOVL concept strongly appealed to many elements of the Royal Air Force, and when the HS.1205 appeared as a late starter in the exercise it rather toppled what we had thought to be becoming a stabilized situation. The question remained as to whether it was at that time a fully practicable solution to the operational requirement, as many of the details had not then been studied in the necessary depth. Subsequent work suggests that adoption of such a proposal would have been decidedly premature.

The twin-engined P.96 type of aircraft was found to have substantial support

An artist's impression of the P.106 light combat aircraft. *(B.Ae.W.)*

A model of the P.96 designed to AST 403. *(B.Ae.W.)*

in Royal Air Force and Government circles. We in industry had our doubts, for it looked like a re-invention of the F-18 and, because of this, unlikely to attract other customers and hence not be a good industrial venture. The United Kingdom design was closely honed to its specified roles, which resulted in its having some facilities not available on the F-18. Much better airfield performance was one important feature of the design, and a much more efficient method for the carriage of bombs was to be provided. Internal or pylon-mounted underwing stores carriage were the norm. The so-called conformal carriage of stores, recessed into the fuselage or wing roots had been mooted, but this required tailor-made recesses for each type of store, and hence was a logistic nightmare and not really practicable. However, an acceptable alternative was developed with under-fuselage stores carried with their upper surfaces close to and tangential with the underside of the fuselage. With an adequate flat-bottomed area, and the ejector rams and carriers mounted internally using an egg-box type of structure to permit a variety of stores configurations, stores drag was little more than that for conformal carriage, and far less than the traditional methods of external carriage. Apart from having to design the aircraft to have the necessary provision for such tangential stores carriage, undercarriage retraction and stowage had to be kept clear of this area. The provision of this facility, and the very short takeoff and landing performance, could not be provided by any existing aircraft.

Our feeling was that, whilst the P.96 design was well matched to the stated Royal Air Force requirements, apart from having poor export potential, it represented the ultimate in a traditional line of evolution.

For the record, the small single-engined aircraft had a wing area of 240 sq ft, span of 25 ft, length of 43 ft, and empty weight of around 14,500 lb, with takeoff weights in the range 22,000-26,000 lb. The larger twin had wing area increased to around 400 sq ft, span 37 ft, length 48 ft, empty weight 21,000 lb, and takeoff weights 31,000-34,000 lb. The STOVL aircraft was of similar empty weight, but — ignoring its ability to be based nearer its targets — required substantially more fuel for the same mission.

It was our opinion that it would be wise to retain the STOVL capabilities of the Harrier and to extend them, without going into the difficulties of supersonic STOVL. This could be done either nationally, for which Kingston proposals existed, or in collaboration with the USA who had embarked on the AV-8B Harrier II programme. This would then leave the path clear for the development of a high-performance STOL fighter with ground-attack capability, which would have better prospects for export or international collaboration. It would also allow for the introduction of more unconventional configurations which would open up new lines of evolution.

Advanced Fighter Studies, ECF, ECA, P.110

Initially the Procurement Executive of the Ministry of Defence, who had been funding the AST.403 studies, refused to back any studies of unconventional configurations, and it was left to industry to find and finance its own way. It was not too long, however, before the Advanced Harrier programme, in conjunction with the American AV-8B, was launched, leading to the possibility of a

two-aircraft solution to meet the needs specified in AST.403. Some government backing to studies of advanced fighters was then forthcoming.

Throughout 1978 and early 1979 British Aerospace and MBB in Germany compared notes, and MBB tabled their TKF 90 design. This had a cranked-delta planform and a variable-incidence canard, but was also designed to manoeuvre at subsonic speeds to very high AOA. For this purpose the wing trailing-edge controls were vented, and additional control under these adverse aerodynamic conditions was to be obtained from three-dimensional vectoring engine nozzles. This super-high AOA manoeuvring in air combat had its advocate in Dr Wolfgang Herbst of MBB; it was designated PST (post-stall technology).

We at British Aerospace, in spite of extensive combat studies and simulations, could not convince ourselves of the benefits of PST, and could see no justification for the increased complexity of controls and the additional weight and cost of the thrust-vectoring nozzles. We had, however, come round to advocating a cranked delta with canard configuration with artificial stability for the next-generation fighter aircraft. This offered better supersonic performance, manoeuvres at higher AOA than hitherto were possible, and new forms of manoeuvre known as direct-force modes.

There was therefore enough common ground for the two companies to join forces in September 1979 and form a dual-nationality study team, headed by Brian Young for British Aerospace and Martin Friemer for MBB. Thus, in December 1979 the European Collaborative Fighter (ECF) proposal was prepared and presented to the two governments. The configuration was very similar externally to the MBB TKF 90, but there were significant differences.

Whilst in the United Kingdom we received some measure of support from the Procurement Executive in these studies, the politicians were insisting on a trinational exercise to include France. As a result, a meeting took place in Paris between M. Cabrière of Dassault, Oscar Friedrich of MBB and myself for British Aerospace acting for Ivan Yates, which led to the immediate actioning of a trinational study team, with Bruno Revellin-Falcoz added to the previous duo of team leaders. The studies ran initially from October 1979 to April 1980, when a report on the study of the European Combat Aircraft (ECA) was submitted to the respective governments. Further work continued until March 1981, when it was decided by the governments that the project was 'not affordable'. It is of interest that, although the earlier Anglo-German studies had produced a definitive design, and the trinational studies resulted in agreed parametric data based on cranked-delta concepts, at no time did AMDBA table any of their configurations, and made it clear that their participation in any ensuing project was dependent upon them being 'given design leadership'. The termination of the exercise avoided further hassle on this childish matter.

The aircraft proposed from the trinational studies had a wing area of around 600 sq ft, a span of 39 ft, length of 49 ft, empty weight of 21,000 lb, and takeoff weights of 30,000-35,000 lb.The programme would at 1984 values have cost some £3,000 million to launch, with production unit cost of £10 million. An in-service date of 1992 was predicted.

Needless to say, the three companies who had been involved did not give up entirely at this but pursued their own individual activities. These led eventually to the Franch Rafaele and the British EAP demonstrators.

During the period of the trinational ECA activities we in the United Kingdom had continued with work on both the lightweight fighter and the supersonic STOVL concepts, within my province the P.106 and P.103 designs, respectively. The situation in 1980 called for a truly total aerospace industry response, and this was the climate in which the various companies joined together in the manner already described.

For a time the lightweight fighter activities predominated, and active discussions began between British Aerospace and SAAB in Sweden, who were in the initial phases of the JAS 39 (later Gripen) project, where we found that we had much in common. We made efforts to find a basis on which to launch a joint project, but unfortunately without success. Nevertheless, four years of this activity did lead to British Aerospace and other British suppliers taking important subcontractor roles in the Swedish project.

The British Aerospace work on the P.106 did, however, show up some shortcomings in the RB.199 engine, which we felt should and could be improved. These coincided very well with what the Tornado project people saw as desirable in the long-term future of their project. Proposals were put to Rolls-Royce, who responded adequately such that we had a datum for the future, although the timescale in which the improved engine would be available remained uncertain.

These engine proposals were, however, to have interesting repercussions in quite a short time. During a visit to London I had informal discussions with a senior member of the Air Staff, and also separately with another in Defence Sales. The latter predicted a worthwhile market within the Middle East for a twin-RB.199 fighter, and he put forward the idea of a stripped-down and 'hotted up' Tornado. The former predicted a possible spending window arising for a fighter, but in a timescale which, he said, would preclude development of a new type, and would force the Royal Air Force into an offshore purchase.

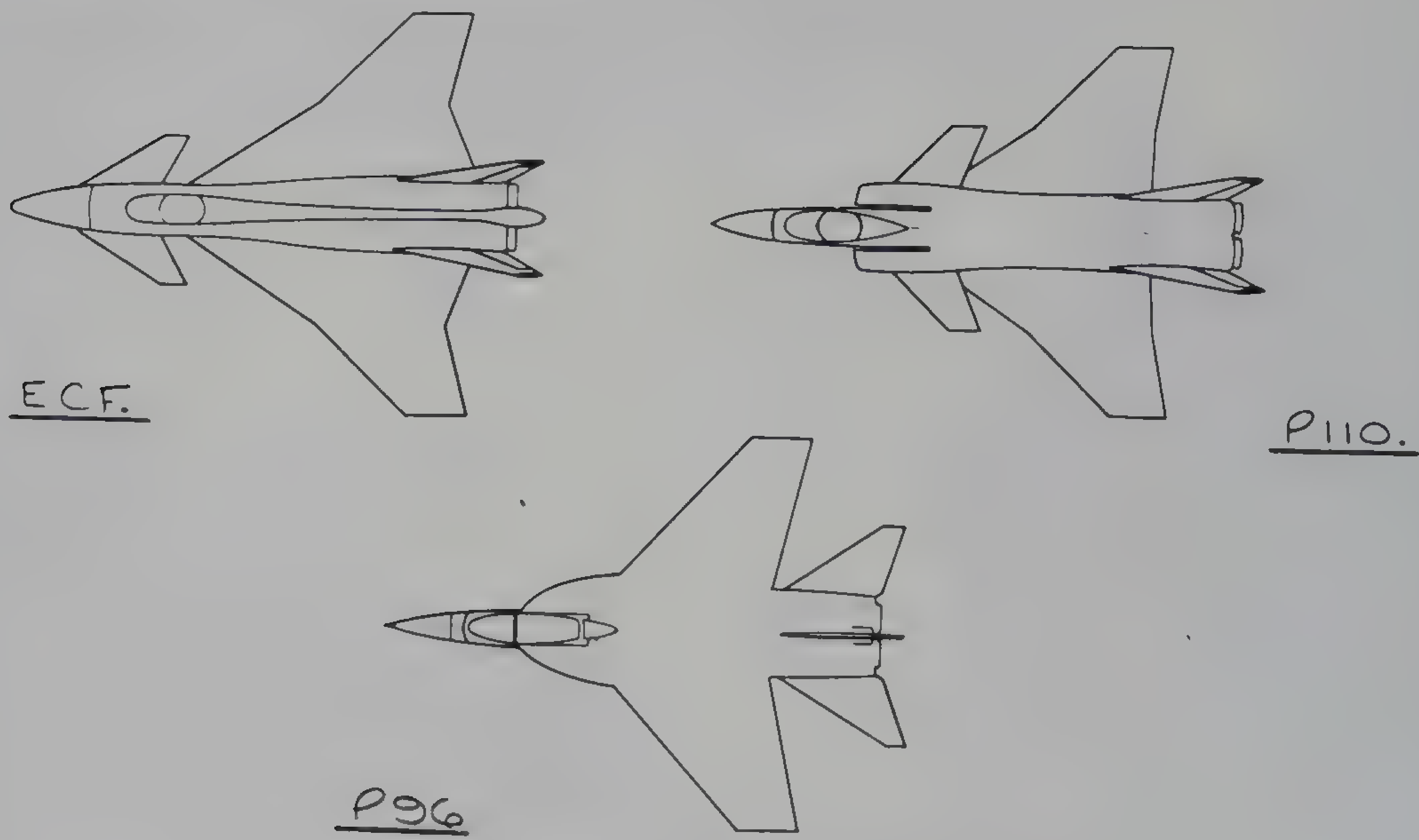
My reaction to these conversations was twofold. First, that the Tornado airframe was not the way to go for a high-agility fighter, although it was ideal for a long-range interceptor, as witness the in-service Air Defence Variant. On the other hand, a design similar to the proposed ECA but scaled down by 33 per cent and engined with the recent Rolls-Royce proposal would really be worthwhile. Secondly, with the recently constituted industrial muscle, we could with a project dedicated team, working on the 'Skunk Works' principle and avoiding the normal Ministry of Defence management procedure, in fact produce the article within the timeframe that my Air Staff friend had mentioned.

I reported back to Ivan Yates. He greeted my proposal with enthusiasm, the organization got to work, and on 16 February 1981 I produced a paper on the basis of which a project launch could be considered. The performance of the P.110 as proposed certainly outshone all of its potential competitors. One of the Middle East potentates was to visit Warton in the near future and we wished to show him a mock-up of our proposal. With the wing from an existing mock-up (the ECF) sawn-off inboard to give the right size, the rear fuselage from the same mock-up, the front fuselage and cockpit from yet another existing source, and a hastily constructed new centre fuselage, it was all joined together in time. The palaver, with the support of our industrial colleagues, began.

After various visits, exercises and conferences, the outcome was that the Middle East nations were not prepared to oil the wheels. They were fully

A model of the Anglo-German European Collaborative Fighter. *(B.Ae.W.)*

A mock up of the P.110. *(CN 18801)*



Comparative plan views, P.96, ECF, P.110

prepared to consider purchase of the P.110 when a flying aircraft could be demonstrated, but they were not prepared to put up the front-end funding for a paper aeroplane. As a result, we were driven back to attempt to generate a domestic market, in aid of which an intensive lobbying campaign was launched based on an office specially commissioned in central London and headed by Don McClen.

The lobbying campaign was successful in obtaining a measure of political support, and also in convincing the Royal Air Force that the P.110 concept had a place in their future fleet. Meantime, the project dedicated team and facilities had been set up and were working flat-out. During the discussions which had been taking place, two things happened to degrade the proposed performance of the P.110. Whilst we had provided an adequate fuel capacity for the interceptor missions, to meet the ground-attack requirements of the Royal Air Force this had to be increased by some 25 per cent. It had also become obvious that the proposed engine development would not take place within the timescale envisaged for the aircraft and that, in the first instance at least, a lower standard of RB.199 would have to be used. Nevertheless, the performance was still good enough to stand up in the market place, and concept looked as if it might go ahead subject to one important proviso — that it must be a collaborative project.

ACA, EAP & Eurofighter (EFA)

The international industrial partnership which had been responsible for undertaking the Tornado project, British Aerospace, MBB and Aeritalia, joined together in June 1982 to prepare proposals for a new fighter and in mid-1983 there emerged the ACA (Agile Combat Aircraft). At this stage the configuration changed from that of the P.110, the side intakes and high and aft position for the canard being replaced by an under-fuselage intake and repositioned


EAP during its first flight, August 1986. *(CN 44537)*

An artist's impression of the Eurofighter. *(OP 1781)*

canard. This intake position was better for very-high AOA work, but it raised the forward fuselage higher off the ground, making access for maintenance more difficult. The MBB TKF 90 had incorporated this intake position for manoeuvring, and it was in fact favoured by our own aerodynamicists, if not by the designers. The alternative low and forward position of the foreplane also followed the TKF 90 design. It did give some cut-off of the pilot's view in the ground-attack mode, although not to a serious extent, and it was quite satisfactory for the air-to-air mode.

The trinational studies and negotiations ground on, with little sign of an immediate breakthrough, even when the industrialists had agreed to a definitive configuration, but in September 1982 the United Kingdom Government announced that it would partially fund a demonstrator aircraft programme, provided that industry would also pay its share. British industry had already organized itself for such an eventuality, but the position of the other partners had to be determined. Both expressed a willingness to join. Originally two aircraft were to be built, one in the United Kingdom and one in Germany, and the UK contract was issued in May 1983. Then, sadly, because of reservations expressed by their government, in December 1983, MBB withdrew their major contribution, although the German equipment companies maintained their support throughout. Italian industry continued to give substantial support to the project, now designated the EAP (Experimental Aircraft Programme) and, with laudable effort and not a little ingenuity in adapting some existing components to fit the aircraft, ZF 534 flew on 8 August 1986. It has since undertaken a very successful programme of demonstration of the technologies proposed for the new fighter. Although not designated as such, it has certainly fulfilled the role of a pre-prototype aircraft for the main EFA programme. It undoubtedly added impetus to the trinational studies which involved industry, the services and governments to enable them finally to agree the specification for the EFA and, hopefully, to get development under way.

The extended timescale and improved financial backing now available meant that the highly developed engine of the original P.110 proposals could be undertaken for application to this project, although early development aircraft would have to fly with then-current RB.199 engines. During 1980 we decided on the standard of the various technologies to be used in the next-generation fighter aircraft, planned the necessary research and development programmes, and ensured that the finance was available. This was an important step in enabling the eventual EAP programme to proceed at the speed achieved.

Concurrent with these activities, and using the same technology base, work continued on the Light Combat Aircraft in association with other countries who were expressing interest in such a project; but the eventual participation of United Kingdom industry in any emerging project remains a matter for conjecture.

Advanced STOVL

Advanced STOVL is the term generally applied to the future aircraft which have a VL (vertical landing) and a supersonic combat capability. The only VL aircraft in service in the Western World is the Harrier, and even its unique capabilities and proven value have failed to capture a sizeable market (although the fleet in

A full scale model of the EFA in the pale grey air superiority camouflage. *(CN 48960)*

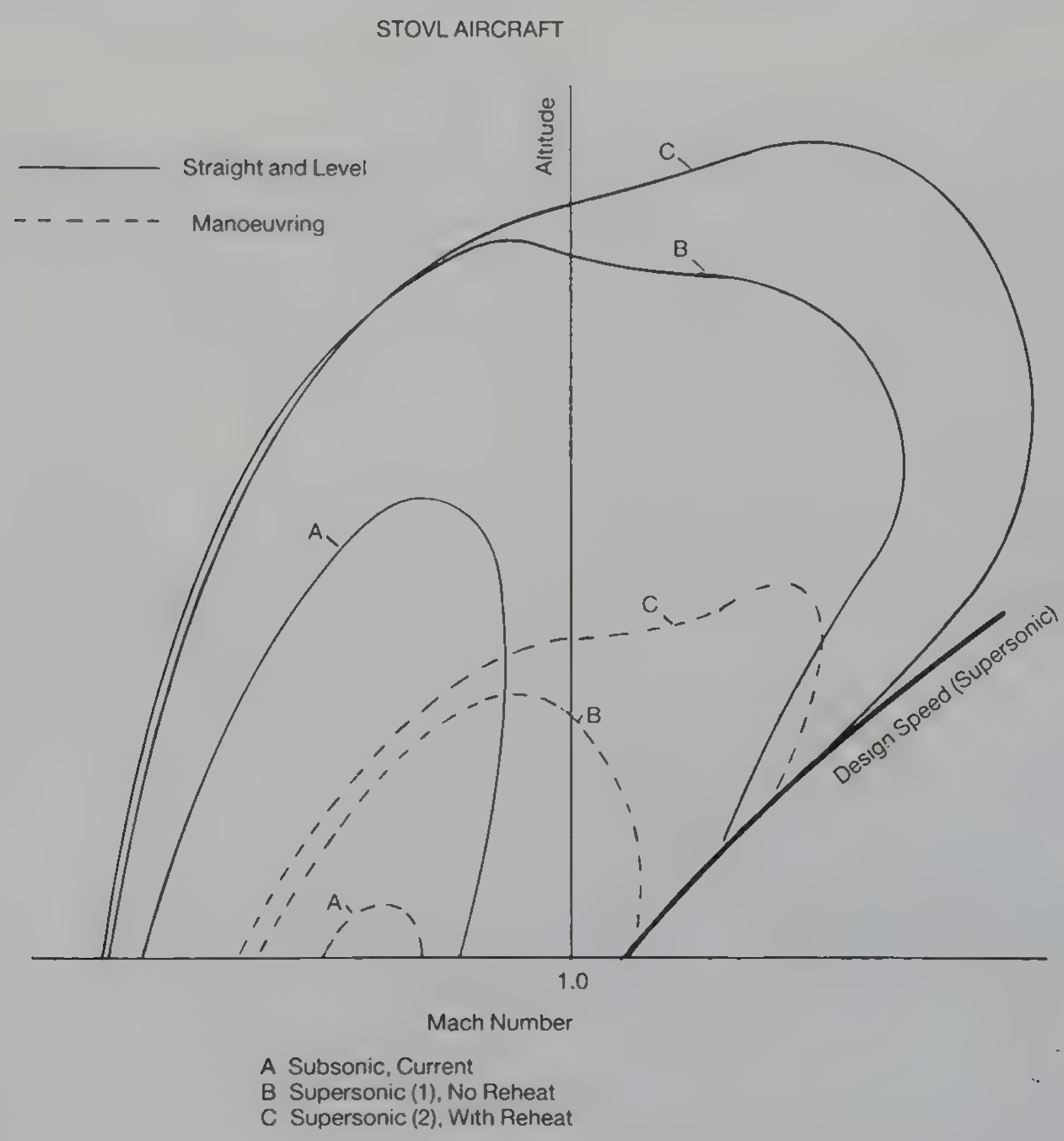
A mock up of the P.103. *(CN 19329)*

the US Marine Corps must not be underrated). To some extent, this must be because operators instinctively feel that, for a given flight performance, a financial penalty must be incurred for a STOVL capability. They fail to comprehend the scenarios where this would be of benefit — probably of vital benefit — to them, at least for land-based operations.

The size of this financial penalty is a matter of debate, for it is like comparing apples with pears. The general, but by no means universal, opinion is that it is currently about 18 per cent on purchase price, and probably something similar on operating costs, although the latter will depend on whether operations continue from base, albeit damaged, or from dispersed sites. But how do you measure this if the conventional aircraft cannot operate, or are all destroyed on their airfields?

For those nations with navies composed entirely of small or medium-sized ships it is a different proposition, but these present a relatively small market. The value of Viffing (vectoring in forward flight) has been shown to be of great value in close air-to-air combat, but the combatants have to get close together in the first instance, to do which may require high performance. Another factor which must have militated against Harrier sales is the fact that it is capable of only subsonic speeds, and the availability on the market of a variety of supersonic aircraft — even useless ones — has proved a bigger attraction.

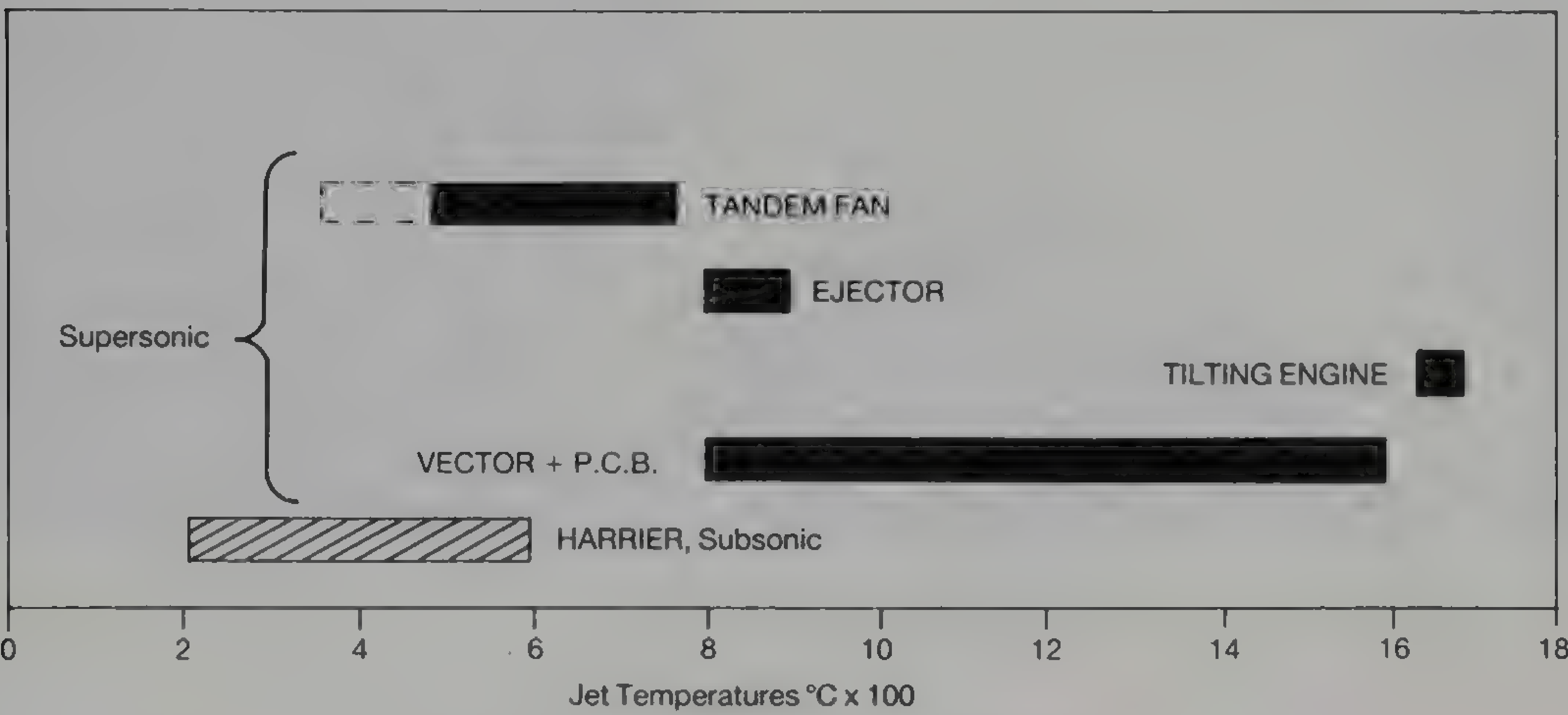
With the probability of severely damaged or obliterated bases increasing with



Maximum level speeds.

time, and with the desire to have the best possible combat performance, attention in recent years has been directed, mainly in the United Kingdom and the USA, to solving the problems of producing a supersonic STOVL aircraft. To the uninitiated this may sound a normal and relatively straightforward progression.

The step forward in combat performance is illustrated by comparing curves A and C in the diagram. Whilst the performance of the Harrier class of aircraft may not look spectacular, the basic simplicity of its propulsion and control systems — arising from a touch of genius and almost certainly luck — have had a lot to do with the Harrier's success. This will not be repeated in any succeeding supersonic project.



Jet temperatures on vertical landing.

To attain this supersonic performance a new generation of engines is virtually inevitable, with higher pressure-ratios, in addition to which some form of reheat is necessary in most of the probable solutions. The exhaust temperatures from the rear nozzles of the Harrier already cause problems on many hard surfaces, and the combination of temperature and pressure have a highly destructive effect on grass surfaces. Next-generation engines are likely to give double the exhaust pressure of the Harrier, with attendant problems.

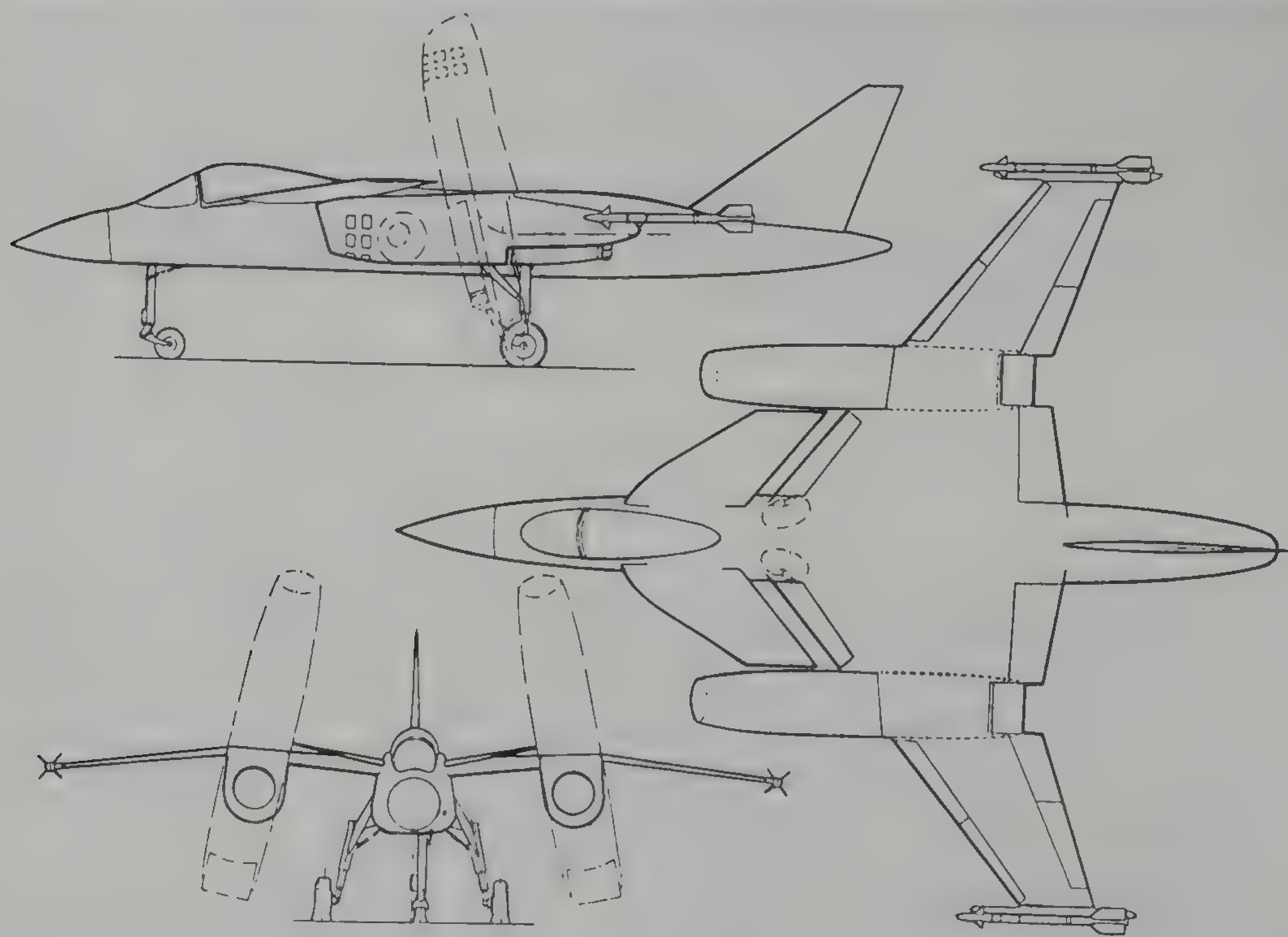
Increased temperatures, due in part to some form of reheat but also from higher temperatures from the basic engine, present a major problem. The range of temperatures likely to be experienced from front and rear nozzles are shown in a diagram. The best-known solutions, the Pegasus with PCB and the tilt engine with reheat, both involve maximum temperatures of 1,600°C or more, compared with the 600°C of the Harrier, and this will certainly require specially prepared surfaces, accentuate the problem of hot-gas reingestion into the engine when hovering close to the ground, and also produce a severe environmental problem for personnel and equipment in close proximity.

The Pegasus/PCB concept has been studied extensively by both British Aerospace at Kingston and by McAIR St Louis. Problems with the 'four-poster' jet layout compatible with low enough drag for supersonic performance restrict the choice of layout, in addition to which hot gas reingestion and acoustic damage to the airframe when using PCB in forward flight have to be catered for.

The tilt-engine solution was explored by MBB in Germany with the rather complex VJ 101 in 1965. In 1977 British Aerospace at Warton began work on the P.103 design. The concept was made possible by the great reduction in the overall length of the engine and reheat pipe, as witness a comparison between the Spey and RB.199, and this permitted wing-mounted engines to be rotated to give the necessary vertical thrust component.

As with all STOVL designs, balance between centre of gravity and thrust line is critical. It was found that a canard layout was more satisfactory in this respect than a tailed design. In some ways this was fortunate, as it was at this time that we were forming the view that the canard configuration was the preferred choice for our next-generation combat aircraft.

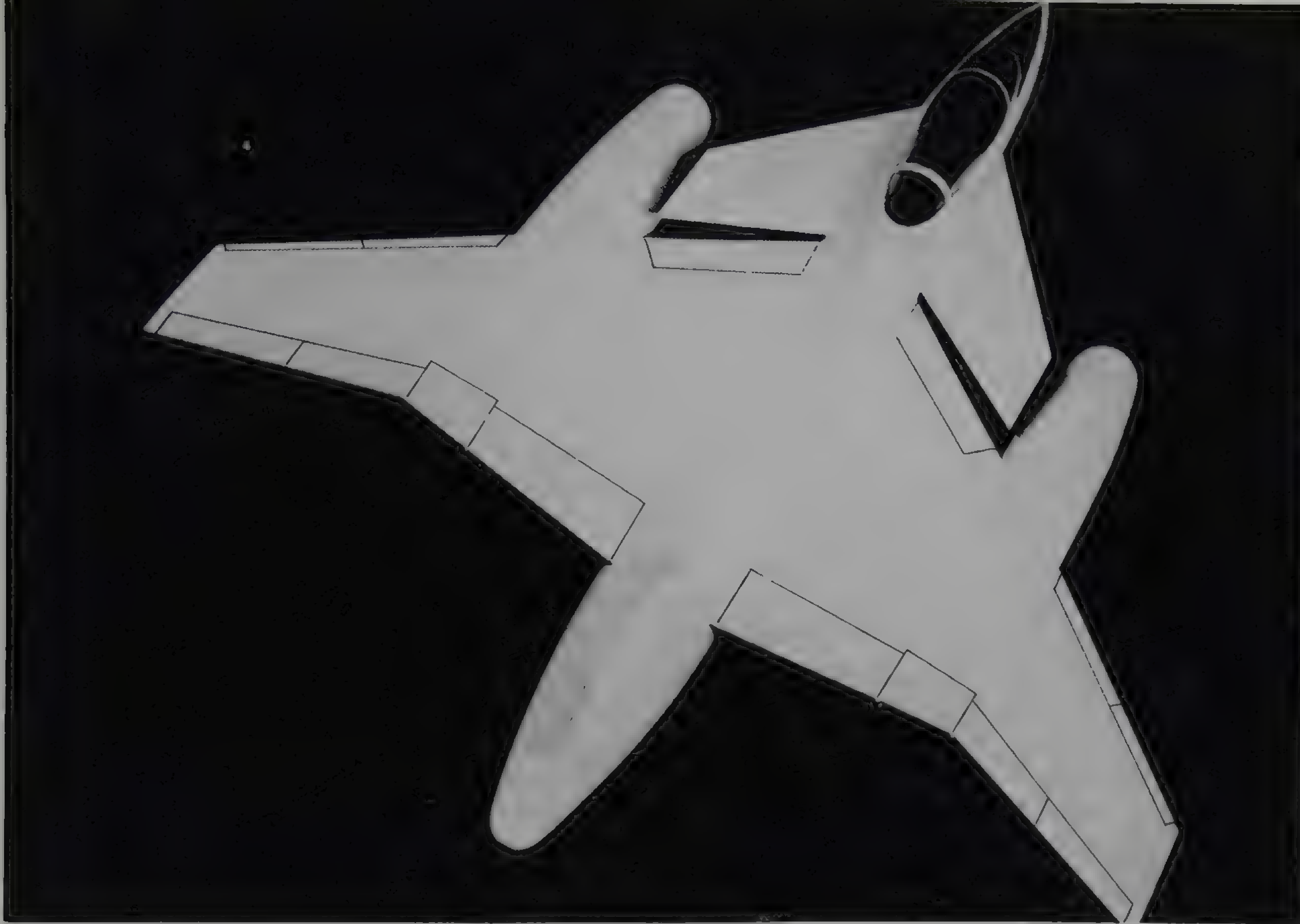
The spanwise positioning of the engines on the wing is decided by the planform in relation to the centre of gravity. The resultant P.103 design places the engines sufficiently far outboard to create a problem if one engine were to fail



The P.103 — general arrangement.

during the hover, causing the aircraft to flip over and preventing safe ejection of the aircrew. However, as with all problems, there is a solution if sufficient attention is paid.

To give a finer degree of control of the thrust vector, in addition to rotation of the engines, a deflector flap was proposed at the jet exit. Initially a two-dimensional (rectangular) nozzle was proposed, very similar to the Aden nozzle which was then under development in the USA. With all of the features involved, including variable area to cater for the reheat, it was studied in depth with Rolls-Royce. It was found to be both heavy and expensive, and a slightly less efficient but lighter and cheaper solution was adopted, with a simple post-exit deflector flap positioned immediately aft of a standard circular nozzle.



A model of the P.103. *(B.Ae.W.)*

A presentation by F. E. Roe, Managing Director, British Aerospace Warton Division, on the author's retirement, June 1984. *(B.Ae.W.)*

During this phase of the work, rig and wind-tunnel tests were undertaken. One rather surprising result emerged. With the jet exit postioned close to the wing trailing edge, and particularly with some downward deflection of engine and/or wing flaps, an entrainment effect on the flow over the wing takes place which improves both lift and drag. Having discovered this in the course of the P.103 design study, we recognised it as a desirable feature to incorporate into other STOVL designs under study, wherever this was practicable.

One problem with the tilting engine is getting engine-driven accessory power into the airframe, there being limited space across the hinge. A different concept of airframe accessory power seemed to be desirable, one solution being to transmit only electrical power across the hinge and to have hydraulic and mechanical packs around the aircraft driven from this source.

One of the delights of the Harrier, as previously mentioned, is the simplicity of the control system. The four main engine nozzles can be rotated by a simple mechanism, and four 'puffer ducts' are mounted at the four corners of the aircraft and supplied with engine bleed air to give the required reactions. Of course, the degree of control required, especially in the then-untried hover condition had to be got right, and this was another area in which the Kingston team distinguished themselves, both in getting it right and also in setting a standard for the future.

On the P.103 the problem had to be solved differently. Even if the engines could afford the bleed air for flying-control purposes, there was insufficient room across the hinge to carry the necessary ducts. Fortunately, pitch control was readily available by manipulation of the post-exit deflector flaps, and for slower trim by rotation of the engines themselves. Lateral and directional control were a different problem, but with the engines mounted fairly well outboard, control could be achieved by appropriate modulation of the engine thrust, should this be found to be practicable.

There was in this concept a further complication. With puffer ducts the control nozzles are fixed to the aircraft's axes, and pilot demand for response in any given plane is made in the normal way. With control coming entirely from the engine nozzles, response to any specific movement of the pilot's controls would vary with the angle of rotation of the engine. With digital computing and electronically signalled controls by now becoming the norm, these provided the means by which this particular problem could be managed. Collaboration between British Aerospace and Rolls-Royce engineers established the design of a completely satisfactory system.

The design and experimental work on the P.103 continued over several years. Hot-gas reingestion tests were included in the programme. With the intakes relatively high off the ground when the engines were rotated for jet lift the problem was considerably eased, and the tests showed that splaying out of the engines a few degrees produced acceptable results.

A full-scale mock-up was built, and the engine rotation demonstrated. Low- and high-speed tunnel tests thoroughly explored the configuration, and the aircraft was flown on the simulator. Satisfactory landings were made by a variety of pilots, including an American general.

The concept of the P.103 was therefore well-proven, although it must be said that some visiting officials looked at it in disbelief. The aircraft was estimated to

be some 1,500 lb heavier than its STOL equivalent, with only slightly lower performance.

Thus Kingston and Warton between them had by the very early 1980s concepts on offer with a VL capability and an attractive supersonic performance, both being based on the application of direct vectoring of the engine thrust, although in totally different ways. Both, however, entrained in their wake severe environmental problems arising from the engine exhaust temperature and pressure.

It is worth considering in this context what the operator really wants when he specifies a VL capability. It is most unlikely that any combat operations will involve vertical takeoff, due to the restrictions on load. Acceptably short takeoff runs, with the aid of natural wind even from ships, can be readily achieved.

Landing, particularly with a combat-fatigued pilot approaching either a damaged or unfamiliar landing area can be a major problem. Accuracy of touchdown, essential if only a short strip is available, can be very difficult to achieve when approaching at, say, 150 mph, although application of some of the techniques which were used by the Fleet Air Arm with simple ground-based sights and unflared landings can make a large difference to touchdown accuracy. On the other hand, with the ability to hover at a reasonable altitude, pick the landing spot, gently reposition the aircraft and then come in to land assisted by powered lift at say, 60 mph or less will greatly ease the touchdown task and give a very short landing distance. This moderate forward speed while jet lift is in operation can make a great difference to the exhaust/ground interaction. It is therefore apparent that an aircraft with a VL performance does not have to go through the agonies of a truly vertical landing to prove its value, and, if it is used with what is called RVL (rolling vertical landing), this would literally take the heat off some of the problems with which we are wrestling. This is perhaps another example where it may be foolish to take a specification too literally.

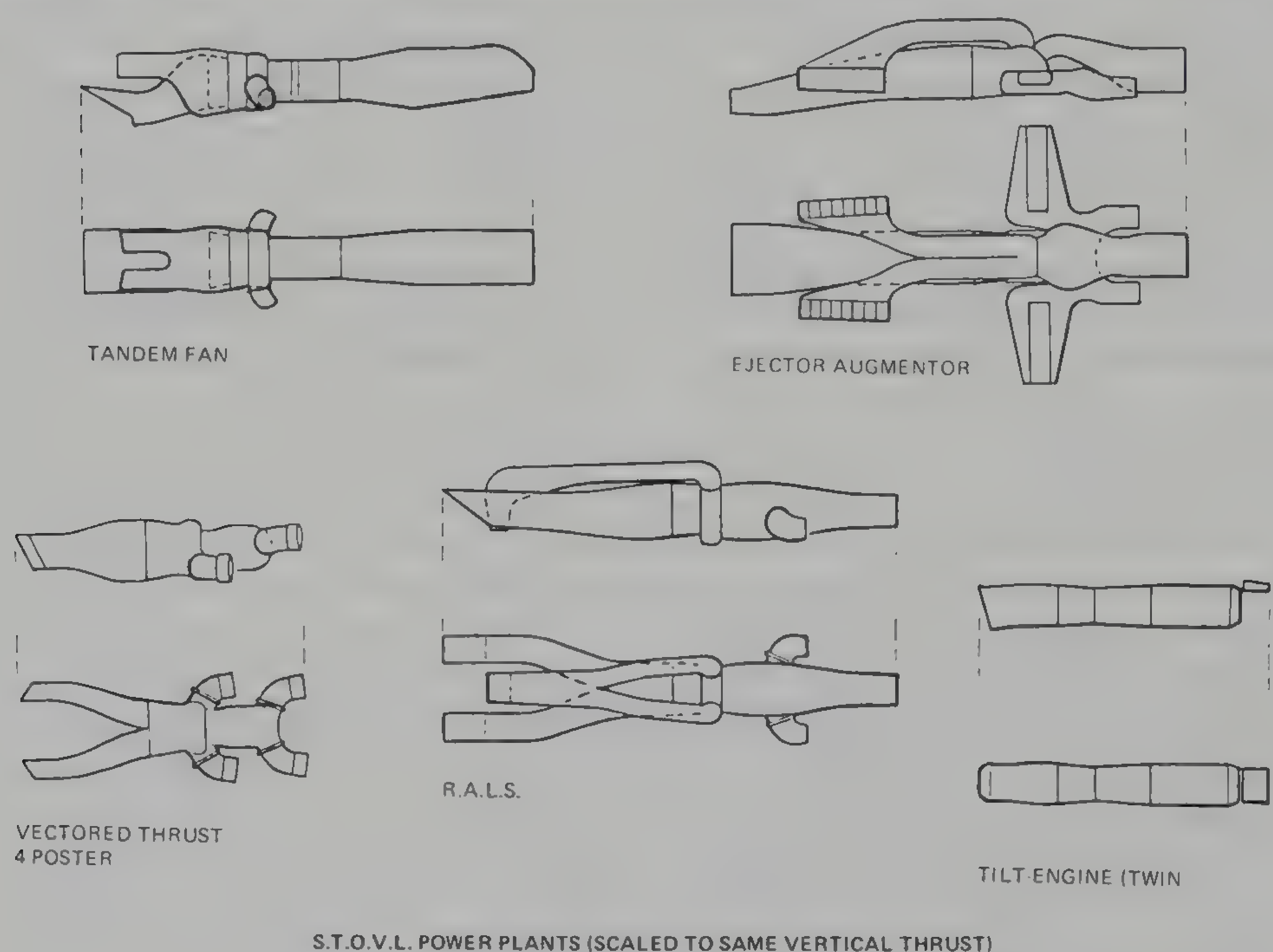
Another form of STOVL design which is under study in both the United Kingdom and the USA uses the RALS (remotely augmented lift system). In this the core flow of the engine is discharged at the rear of the aircraft and then vectored for takeoff and landing. In normal flight the fan or bypass air is also discharged at the rear, but, for the jet-assisted lift case, a diverter valve at the engine operates and the air is ducted forwards and discharged in a high-energy vertical jet after fuel is burned in it in a manner similar to that for PCB. This forward nozzle must be positioned to give the right balance with the vectored core flow. Apart from the problems of diverter valve design and the volumetric requirements of the ducting, to assist transition from jet-borne to normal flight some degree of fore and aft vectoring of the front nozzle thrust is highly desirable. To this snag we must add that of the temperature of the front-nozzle exhaust in terms of ground compatibility and hot-gas reingestion.

The concept is well matched to the canard delta configuration. For instance, the core flow from the rear-mounted engine might be bifurcated to Harrier-type nozzles positioned inboard at the wing trailing edge to give a degree of the favourable jet/wing interaction, but with the bypass air still being discharged in the conventional rear position. Reheating this bypass flow only would boost the performance considerably, and is thermodynamically more efficient than reheat applied to the mixed core and bypass flow. This principle is also used for the four-poster vectored-thrust arrangement when PCB is used in forward flight.

Using this type of configuration it is not inconceivable that, in time, a major variant of the Eurofighter could be developed. Estimates suggest that such a programme could provide a supersonic STOVL fleet at 15-20 per cent less cost than with a completely new design. Whilst RALS can be seen to have some of the disadvantages of the two vectored-thrust solutions discussed, it also has enough attractions to keep it in the lists of candidates under consideration for next-generation STOVL designs.

The ideal solution is to have a supersonic aircraft with a much more benign footprint on the ground, and in parallel with the three configurations already discussed, two such concepts, the ejector-augmentor and the tandem fan, are currently included in the studies in hand.

An illustration shows the plan views of the power installation for each of the five concepts, with each scaled to give the same vertical thrust in the jet-lift mode. The two simple vectored-thrust schemes require roughly the same



STOVL power plant, side elevation and plan views.

volume; RALS, on account of the ducting, needs some 90 per cent more. The ejector-augmentor, if it can be made to work (and it is a high risk in that respect), will give a relatively benign footprint, although still much worse than that of the Harrier, at the expense of 110 per cent increase in installed volume. The tandem fan could be the best solution in terms of footprint, even if some fuel is burned in the forward nozzle, and this arrangement can be obtained with a 70 per cent greater volume than that of the simple vectored-thrust schemes, but it does require some sizeable mechanical and aircraft structural problems to be overcome.

Demonstrator prototypes of the ejector-augmentor principle have been tested in the past with the Lockheed XV-4 Hummingbird and the Rockwell XFV-12A.

Neither can be regarded as having been successful, although the reasons for this are now, in the main, understood.

The principle of the ejector-augmentor is to duct high-energy air from the engine into a mixing chamber followed by a diffuser. Here the high-energy air entrains ambient air to multiply the mass flow by between six and ten. Hopefully the result is an increase of thrust of between 1.0 and 1.5, with a large reduction in exhaust temperature and hence a more benign footprint.

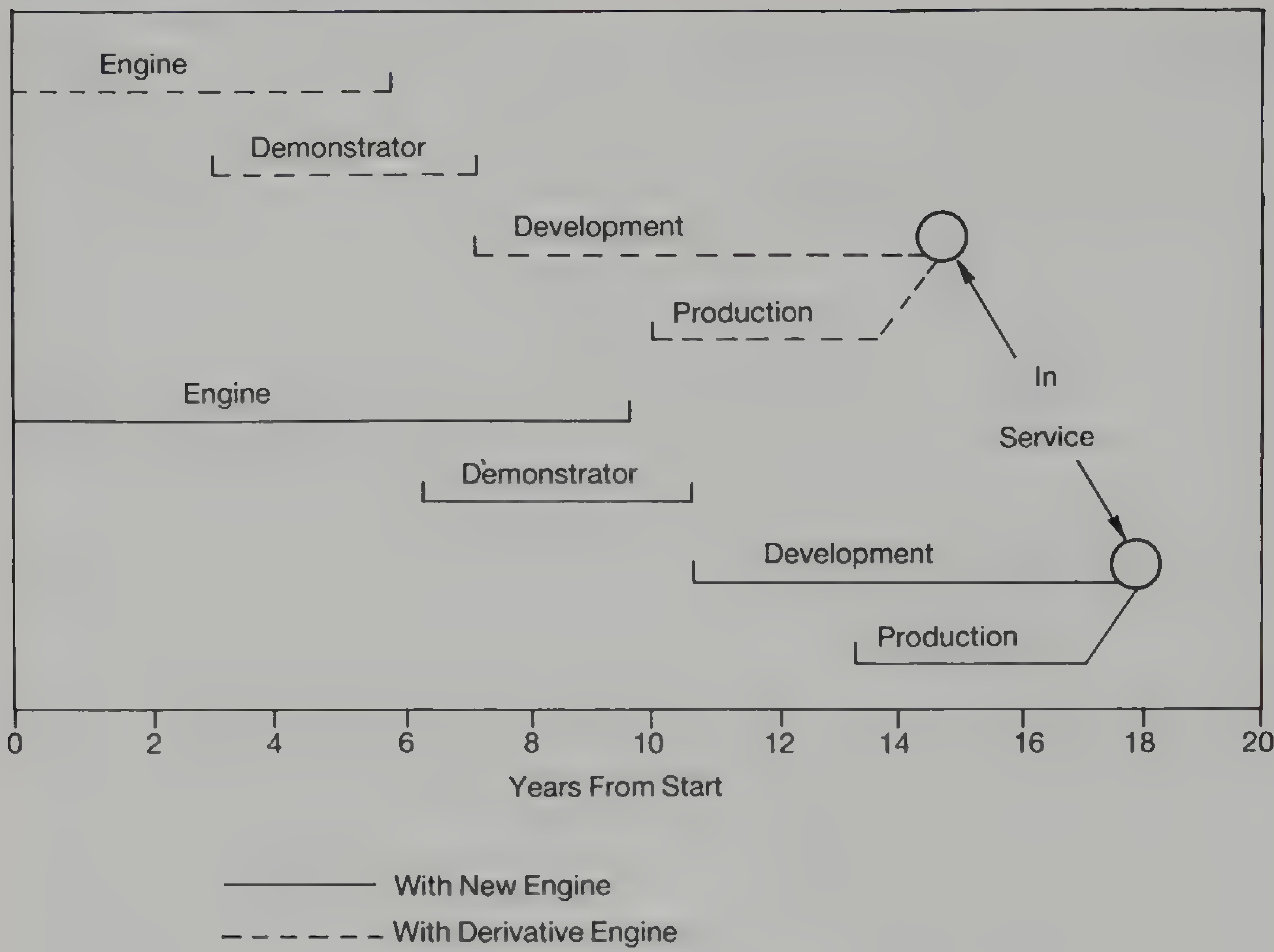
It is possible to use purely bypass air for the ejectors, with normal vectoring of the core flow, but this reduces the footprint gain. More gain could be obtained by also using the core air in an ejector and thereby diluting the temperature further. However, the engineering problems of ducting this high-temperature gas to the locations required do not at this stage have an obvious solution. The design of ducting, ejectors and diffusers is critical to the performance, and this in many ways increases the difficulty of installing such a system in a supersonic aircraft. Nevertheless, the concept has its attractions and remains a possible candidate under study, although at the moment it cannot be regarded as a front runner.

The tandem fan is another concept which is still in the early stage of development. It consists basically of an engine which can operate in two entirely different modes. The series mode is when all of the air passes through the engine. In the parallel mode, air from the normal intake passes through the front fan and is then ducted down to a jet-lift nozzle. A separate intake is then opened, in conjunction with a diverter valve, to supply the engine core. In the jet-lift mode this core flow is vectored in such a way as to balance the trust from the front jet.

Designers problems encompass the diverter valve, the secondary intake for the core flow and the forward nozzle, which could take a range of forms such as the fully vectorable Pegasus type of nozzle or a letter-box slot arrangement on the fuselage underside, with possibly a limited vectoring capability. The possibility of employing thrust augmentation, either by fuel burning or ejector-augmentors with the front fan exhaust has been investigated, but any such additional device would appear to be unlikely. The engine itself becomes longer than its conventional counterpart, with an extended shaft to the front fan to allow room for the diverter valve and the duct to separate the front and rear fan flows, in addition to the requirements for the secondary intake.

In principle the concept has the advantage that the basic engine cycle can be designed for the forward-flight case, although, in practice, design of the front fan system for the hovering case may limit the degree of freedom. The precise place of the tandem fan in the spectrum of choice is at this stage uncertain. As with other concepts which have been studied, it has its pluses and minuses, many of which remain to be quantified.

From the foregoing it will probably be deduced that the future of advanced STOVL is open to some doubt. Is there a big enough market for it to justify the large development costs involved? If the answer is in the positive, it is almost certainly heavily weighted in favour of the USA, particularly if the Air Force and/or the Navy join the club. If this is so, they will have a strong say in the choice of system to be adopted. Whist joint Anglo/American investigations are proceeding all contributions must be relevant, and we can only participate and await the outcome.



Programmes for advanced STOVL.

Whatever the final choice of system may be, it will encompass a major engine development programme. Some STOVL solutions demand a particular engine cycle or bypass ratio, for which a new engine is likely to be necessary. Others will be satisfied with a variant of an existing engine, although this could well be a completely new arrangement around an existing core. Any programme is likely to involve an engine development programme and a demonstrator aircraft — to prove the concept by, say, a one year's flight experimental programme — before a fully operational aircraft development and production programme is embarked upon.

A possible programme based on these assumptions is illustrated both for a derivative and for a new engine application. It shows a period from project start to entry into a service of 15 and 18 years, respectively. It may be some time before the concept to be used, and hence the engine development requirements, are defined. In the meantime, Harrier type STOVL and its possible developments will continue to be deployed.

Chapter 14
In Conclusion

Over 40 years passed between the time that I first set foot on an aircraft factory floor until I retired. During this time the nature of aircraft has changed dramatically, with an equally dramatic change in the shape of the aerospace industry. The future appears to be uncertain, but it has in fact always looked that way — although over the years the perspective has changed somewhat. I can only hope that my successors can have an as interesting and varied career. In that context some profound questions will need to be answered.

For example, is there a requirement for a future generation of combat aircraft, or are we destined — as some thought in 1957 — to have entirely push-button warfare, either earthbound or in outer space? The space battle question must be left to the superpowers, albeit with contributions from their smaller allies. Be that as it may, none of the superpowers is showing any sign of abandoning the fighter-bomber class of aircraft.

The great thing with the manned aircraft is its flexibility in terms of location when the need arises, and in the variation of the tasks which it can perform. Intelligent and autonomous-after-launch weapons will certainly play their part, many having an option of air or ground launching. We must never forget that it is the unexpected that is most likely to happen, and the portable and versatile manned aircraft can be a priceless asset.

The overwhelming problem is to decide what performance and capability are really necessary, bearing in mind the long in-service life to be catered for, and then to produce it at a price which is affordable. This means a reversal of the trends of recent years, and will fully stretch the capability of everyone involved.

With the infrequency of new projects which is likely to continue, a healthy and prosperous industry needs to be engaged in updating existing products, which must also be of benefit to the operators. The problem of them having sufficient aircraft to allow retrofit programmes is a separate but related issue, which must be faced.

In the writer's mind at least, doubts remain of a supersonic and vertical landing project maturing in this century, but this and all other opinions expressed are his own, and not necessarily those of any organization for or with whom he has worked.

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B.2	Trainer 1932 (54)
B.54	Anti-submarine aircraft to Specification GR.17/45 (34)
B.75	Five-seat transport 1947 (37)
B.77	Rapide replacement 1948 (39-40)
B.80	Basic trainer to Specification T.16/48 1949 (54)
B.81	Naval search aircraft 1949
B.82	Naval fighter to Specification N.14/49 1949 (62)
B.83	Light anti-submarine aircraft 1949 (34-35)
B.84	Rapide replacement for BEA to Specification 26/49 1949 (40-41)
B.85	Composite tail first aircraft 1950
B.86	Coastal Command aircraft 1950
B.87	Trainer 1950
B.88	AEW adaptation of GR.17/45 aircraft 1950 (34-37)
B.89	Naval fighter to Specification N.114T 1950 (61-63)
B.90	Supersonic research aircraft 1951 (57-58)
B.91	Light anti-submarine aircraft 1951 (34)
B.92	Jet trainer 1951 (54)
B.93	Five-seat transport ex B.75 1951 (37-38)
B.94	Undercarriageless naval fighter 1951 (62-63)
B.95	Naval fighter 1951 (62-63)
B.96	GR.17/45 with Napier E.141 engine 1952
B.97	Rocket interceptor fighter to Specification F.138D 1953 (57-59, 63)
B.98	Passenger version of GAL 60 Universal 1952
B.99	Naval interceptor fighter 1952 (63)
B.100	Civil freighter version of Blackburn Beverley 1952
B.101	Military freighter version of Beverley 1952 (47)
B.102	Naval all-weather interceptor 1952 (63)
B.103	Naval strike aircraft/NA.39 Buccaneer 1952 (46, 50-51, 63, 66, 85-92, 94)
B.104	Military freighter to Specification OR.323 1953 (47, 49-51)
B.105	Eighteen-seat feeder liner 1953 (40, 42)
B.106	26-seat feeder liner 1954 (40, 43)
B.107	Tactical and strategic fighter 1956 (50-51)
B.108	B.103 development for the RAF 1957 (63-65)
B.109	B.103 variant with RB.146 engines for Canada 1958 (64-66)
B.110	28-seat civil transport 1958 (44-45)
B.111	B.103 variant with reheated RB.168 engines to Specification OR.333 1958 (64, 66-67)
B:112	B.103 variant for naval combat patrol 1958 (64, 66-67)
B.113	B.103 variant for Australia 1958 (64, 67)
B.114	Jet flap Anson replacement 1960 (45-46, 51)
B.115	Cold jet flap experimental aircraft 1960
B.116	B.103 variant for the German Navy 1960 (64, 67)
B.117	B.103 high-altitude fighter variant 1960 (64, 67)

B.118	Vertical rising transporter 1960
B.119	Naval AEW aircraft 1960 (34-37)
B.120	Anson replacement 1960 (46)
B.121	Beverley/Argosy replacement 1960
B.122	STOL freighter 1961 (51-53)
B.123	Advanced strike aircraft to Specification OR.346 1961 (69-70)
B.124	Major variant of B.103 1961 (68)
B.125	STOL freighter to NATO requirements 11961 (51, 53)
B.126	Land-based Buccaneer development 1961 (68)
B.127	Variable geometry development of Buccaneer 1962 (68)
B.128	Buccaneer with RB.168 and reheat 1962 (68)
B.129	Supersonic development of Buccaneer Mark 2 1962 (68)
B.130	Advanced strike aircraft 1962
P.131	Subsonic, low-level strike aircraft 1962
P.132	STOL development of Buccaneer 1962 (68)
P.133	Buccaneer Mk 2 assisted takeoff 1962 (68)
P.134	Buccaneer Mk 2 with improved weapons system 1962 (68)
P.135	Variable sweepback strike fighter 1962 (69-70)
P.136	Buccaneer Mk 2 for South Africa 1962 (68)
P.137	Project number unused
P.138	Counterinsurgency strike fighter 1962
P.139	AEW aircraft 1963 (34-37, 165, 194)
P.140	Supersonic naval fighter development of Buccaneer 1964 (68, 178)
P.141	Tactical support and strike aircraft 1965 (70-71)
P.142	Supersonic version of Buccaneer 1965
P.143	Buccaneer fuel and stores pallet 1966
P.144	Project number unused
P.145	Land-based Buccaneer development 1966 (169-171, 177)
P.146	Light tactical aircraft 1967 (59-60)
P.147	Basic trainer 1967 (55-56)
P.148	Retrofit of Spey engine to Buccaneer Mk 1 1967
P.149	Development of RAF Buccaneer 1968 (174-177)
P.150	Supersonic Buccaneer for RAF 1968 (178-179)
P.151	Semi-strategic strike aircraft 1969
P.152	Light tactical aircraft 1971
P.153	Low-level interceptor fighter 1970 (76-79, 83, 229)
P.154	Simple strike aircraft 1971 (60, 229)
P.155	Base burning aircraft 1971
P.156	168-73R Spey-engined fighter 1972
P.157	Close air support and strike development of Buccaneer 1974 (177-178)
P.158	Twin-engined fighter, also HS.1207 1974 (230)
P.159	Small combat aircraft, also HS.1204 1974 (79)
P.160	Vectored lift fighter to Specification AST.403 1976
P.161	Canard aircraft configurations 1979
P.162	Variable-cycle engine configurations 1979
P.163	Small air combat aircraft 1979 (79)
P.164	Trainer 1980 (56)

The Author

Roy Boot entered the aircraft industry in 1941 as a student apprentice with Cunliffe Owen Aircraft Ltd. Here he worked on modifications to aircraft of American origin while also studying aeronautical engineering at University College, Southampton, from where he graduated in 1944. On graduation he was directed to join the staff at the headquarters of the Ministry of Aircraft Production, spending two years as a backroom boy on fighter development in the period when jet propulsion and compressibility entered prominence.

From 1946 to 1949 he worked at Airspeed Ltd. at Christchurch on performance, technical sales and project work on the Ambassador airliner and projected developments.

In 1949 he moved to Blackburn Aircraft at Brough where he remained until 1978. Initially leading the Future Projects Office, when the NA39 (later Buccaneer) emerged as an ongoing project, Roy played a prominent role in the development team whilst retaining involvement in future project thinking. He was promoted to Assistant Chief Designer in 1962, Chief Designer in 1966 and Executive Director and Chief Engineer in 1968.

From 1978 to 1984 he was Executive Director New Aircraft at British Aerospace, Warton, heading their activities on AST 403, early collaborative studies for a multinational European fighter, a light combat aircraft and next generation STOVL designs, work which included establishing integrated activities of airframe, engine, weapons and equipment units of British Industry.

He has lectured on related subjects in many countries.

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